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Journal
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Vol. 205 JANUARY, 1928 No. 1

THREE CENTURIES OF NATURAL PHILOSOPHY.

FOUNDERS' DAY ADDRESS, SWARTHMORE COLLEGE,

OCTOBER 29, 1927.

BY

W. F. G. SWANN, D.Sc.

Director, Bartol Research Foundation of The Franklin Institute.

THREE thousand years ago there died in Egypt a king. He was buried with much pomp and ceremony, and in the company of such material things as reflected the atmosphere of his time. After thirty centuries, untouched except for the minor vandalism of robbers, these relics speak to us the story of an age which has passed. They tell us of a skill in craftsmanship equal to our own, of a beauty in art and in concept of design such as wins the admiration of our most famous artists; and reading the evidence of a little act here and a little thought there, we begin to see a people such as we could well have known as friends—a people of whom who can say that if one of them were born to-day and raised with our children he would be distinguishable from one of us. Yet, neither in the age that knew Tutankhamun, nor in any of the ancient civilizations that have gone before or after, do we find any shadow of a concept of that great scheme of nature's laws which has unfolded itself so unsparingly in our generation.

If the period from the dawn of history to the present time be shrunk into a day, we shall find that twenty-three hours of that

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day are barren as far as natural philosophy is concerned, for it is only in the last hour that science was born; and, even as the human child develops in its struggles toward manhood, so this child of nature has grown, but with such ever-increasing strength that in the last ten minutes of its existence, in the last twenty-five years of actual time, it has outshone all the accomplishments of its infancy and adolescence and has torn from nature more of her secrets than she has vouchsafed to man in the whole previous history of his existence.

Three hundred years ago we find the world just emerging from the state in which he who would search for the hidden truths of nature must contend with three great obstacles—superstitution, the power of the church, and, last but not least, a conglomeration of fixed notions as to the way things should happen, built upon the pseudo-philosophical reasoning of bygone ages, reasoning founded not upon experimental bases, but upon dogma evolved out of the imaginations of the philosophers.

The train of scientific thought was founded largely upon the hypothesis that the writings of Aristotle were to be the ultimate court of appeal in all matters of dispute, and wondrous indeed were some of the things which Aristotle and his disciples had said. A good example of some of their misty philosophizing is the proof given by one of them that the world is perfect.

"The bodies of which the world is composed are solids, and therefore have three dimensions. Now three is the most perfect number; for, of one we do not speak as a number, of two we say both; but three is the first number of which we say all. Moreover, it has a beginning, a middle, and an end."

Towards the end of the fifteenth century we find young Galileo enjoying the princely stipend of fifteen cents a day as professor of mathematics at the University of Pisa. It is true that the professor of medicine gets thirty times as much, and Galileo's parents had originally intended him to be a professor of medicine. But what does he care! For he is much interested in discovering the laws of falling bodies; and, in spite of the fact that Aristotle has said otherwise, he is contending that heavy bodies and light bodies fall at the same rate. In scientific circles much resentment is felt at such a revolutionary suggestion; for Aristotle, without appeal to experiment, has evolved out of the consciousness of his inner mind the decision that bodies fall

at rates depending upon their weights. It matters not that young Galileo has ascended the leaning tower of Pisa with a one-pound weight and a hundred-pound weight and, in full view of the learned men of the day, has dropped them from the tower and found that they struck the ground together. For Aristotle has maintained otherwise, and science is the voice of Aristotle.

Neither is there more tolerance in the matter of astronomy. For Galileo has invented and constructed a telescope; and though he has received much honor from his university for this performance, and has had his salary doubled, there are many who not only refuse to accept what the telescope reveals, but steadfastly refuse to look through it lest they should be convinced of the truth of that which they do not wish to believe. With this obnoxious machine Galileo has found that the moon has mountains like the earth, which robs that body of some of its individual importance. He has found spots upon that most perfect of heavenly bodies, the sun, but worst of all he says that Jupiter has four moons attendant upon him. This last conclusion is in a way to upset everything. Though too much of a man of progress to doubt the evidence of his own eyes, even the great Kepler is disturbed in his mind. For, according to all prevailing notions of the day, there should be seven planetary bodies and no more—the earth, moon, Mercury, Venus, Mars, Jupiter and Saturn.

Hear the argument of Francesco Sizzi, himself a Florentine astronomer, against this assertion of Galileo:[1]

"There are seven windows in the head, two nostrils, two eyes, two ears, and a mouth; so, in the heavens there are two favorable stars, two unpropitious, two luminaries, and Mercury alone undecided and indifferent. From which, and many other similar phenomena of nature, such as the seven metals, etc., which it were tedious to enumerate, we gather that the number of planets is necessarily seven.

"Moreover, the satellites are invisible to the naked eye, and therefore can have no influence on the earth, and therefore are useless, and therefore do not exist.

"Besides, the Jews and other ancient nations as well as modern Europeans have adopted the division of the week into seven days, and have named them from the seven planets; now

[1] Quoted from Sir Oliver Lodge's "Pioneers of Science."

if we increase the number of planets this whole system falls to the ground."

You can judge of the wrath and indignation which Galileo brought upon his head when he contended in reply that, whatever might be the force of these arguments as a reason for believing beforehand that no more than seven planets would be discovered, they hardly seemed of sufficient weight to destroy the new ones when seen.

It was Galileo who wrested from nature the secret of the laws which govern motion—the laws which govern the motions of almost everything, the planets in the heavens, the fly wheel of the steam engine, the bird in flight—yes, and in a large measure at any rate, the motions of the innermost parts of the very atoms of matter itself. But Galileo did not evolve these laws out of the dogmas of imagination, but by the more humble and safe appeal to direct experiment. He marked out the method of approach, the experimental method, which has been the model for all succeeding generations in their search for the fundamental facts which govern the workings of nature.

The laws of motion may be written on a postcard, but their consequences have not been exhausted in all the books men of science have written in three hundred years. As we all know, Galileo's life was beset with tribulation. He lived in an age when there was little tolerance for one who followed not the conventionalities of thought of the day. To question the learning of the past was arrogance, to discover new truth was blasphemy, and so he died having sown, however, the seeds of the fruit that was to come. He died in a world seething with superstition and ruled by the dogmas of an ancient past, but a world which was destined only a year later to see the birth of one who is rated by many as the greatest genius of all time—that great prince of England's men of science—Isaac Newton.

In its purest aspect, the task of the natural philosopher to-day is to discover the relationships existing between the different phenomena which happen in our universe. He seeks to see in the workings of nature simply different illustrations of a few fundamental principles. Newton was the greatest of the pioneers in this method of systematized thought. In his great work, the "Principia," characterized by the Marquis Laplace as pre-eminent above all productions of the human intellect, he demon-

strated the powerful simplicity of the fundamentals which control the destinies of the heavens. No longer did the universe appear as a bizarre and formless thing governed by such a heterogeneous system of agencies as to merit well the caustic comment of the sovereign of Castille when, bewailing the complexities involved in an attempt to explain the motions of the planets, he remarked that "Were the heavens thus constituted, he could have given the Deity good advice."

No longer need the sun carry spokes, as Kepler thought, to grind the planets around in the heavens. No longer was a guardian angel necessary for each planet to guide its course. No longer were the planets whirled through space by the whirlpools of an ether as a twig is whirled about in the rapids. All that was necessary was the laws of motion of Galileo, operating under the influence of a force emanating from the sun according to the inverse square of the distance therefrom. And this force was no new and mysterious thing, for Newton showed that gravitation, that same old force which had been known for so long—gravitation which causes apples to fall from the tree to the ground—was sufficient to control the moon in its orbit, and such a gravitation with its origin in the sun served the purpose of controlling the planetary motions. Moreover, in this same gravitation did the tides find their origin through an attraction of the moon. In this same gravitation from the sun, combined with the flattened shape of the earth, did that mysterious conical motion of the earth's axis concerned with the precession of the equinoxes find its origin, and in the laws of Galileo was to be found an explanation of the actual flattening of the earth's shapes as a result of the centrifugal force of its rotation. These and many other things did Newton demonstrate in the "Principia" and by their means brought astronomy from a state of pure charlatanism to the state of order symbolized by Pope's famous words, "Nature and Nature's laws lay hid in light, God said: 'Let Newton be' and all was light."

Even as our greatest architects strive for beauty couched in a fundamental simplicity of design, so the Grand Architect of the universe revealed himself in Newton's great work as the father of the principle of dignity of structure through ultimate simplicity. It is a great faith in the possibility of seeing in the operations of nature the working of principles which are ulti-

mately simple which, as each new discovery is revealed, has encouraged man to the hope that he may some day understand them.

While to-day nature has revealed many treasures unknown to Newton, there are few who, realizing the great stride made in the "Principia," will not to-day join with Halley in his eulogy of that great work, "So near the gods man cannot nearer go."

When an outstanding genius causes science to take a leap forward beyond the vision of his contemporaries, there usually follows a period of depression in which it seems that all that is worth doing has been done, and that what the universe has not already revealed must forever defy the power of man to fathom. Such a period followed Newton. Of course, much valuable work was done in the years which came after, but it took more the form of a development of the consequences of Newton's labors than of the discovery of new paths of knowledge. And then, only about a century ago a new page in the architectural designs of the universe was turned, and the heading on that page was *electricity*.

The forerunners in the march of science do not often come heralded by much ceremony suggestive of the power that lies behind them. Often in apparent trivialities do they reveal themselves—trivialities so void of spectacular content that but few can be found who deem it worth while to listen to their story. A hundred and fifty years ago little more was known of the science of electricity than the fact that if a black rod is rubbed with the skin of a cat it will acquire the power to pick up small pieces of paper, and, if viewed in the dark, will be found to emit a blue glow. One can hardly imagine a set of phenomena more vulnerable to the scoffer; for, black rods and cats have been the stock paraphernalia of witches from time immemorial—the blue light visible in the dark adds no particular prestige to the phenomena. And then, we find that these things will not reveal themselves in the presence of water. Now, we should say that water destroys the electrical insulation, but the scoffer who had heard so much of the fundamentality of that triumvirate, "earth, fire and water," might find ample wherewithal to whet his sarcasm, and even though he should admit the reality of the phenomena themselves, he might well attack them on the basis of their futility, for it would appear that if all the black rods in the world were rubbed with the skins of all the cats, the most that might hope to be

accomplished would seem to be the raising of a small weight of totally insignificant amount. And yet, on this earth at that very time there existed, and within the reach of man, the wherewithal to make a dynamo.

To one who contemplates the enormous manifestations of electrical power to-day, it seems almost inconceivable that all of these potentialities could have remained dormant for the whole period of man's civilization.

The Royal Institution of Great Britain was founded by Count Rumford in 1799. Its stated purpose is "the promotion, diffusion, and extension of Science, and of useful knowledge." To its lectures given by Sir Humphry Davy at the beginning of the last century came a young bookbinder's apprentice, whose enthusiasm sufficiently impressed the lecturer to result in his being appointed as assistant at the Institution. Unfortunately, it became necessary for the young man to have some money wherewith to live, but there was no money for scientific assistants. However, the Institution had an appropriation for janitors and so the bookbinder's apprentice, Michael Faraday, became janitor at the Royal Institution. I do not know how efficiently he performed his duties in the office of janitor, but even though he may have neglected the windows of the laboratory, he cleaned well the windows of science, and even though he may have neglected the cobwebs on the walls of the building, he cleaned many of them from the horizon of knowledge.

The fact that wires carrying currents possessing in many respects the characteristics of magnets was already known, but it fell to Faraday to discover the fact that batteries were not the only means by which electric current could be produced, and to demonstrate the fundamental principles upon which electrical engineering is based to-day. By the labors of that little group of men, Ampère in France, Faraday in England and Henry in this country, we came into possession of most of the facts governing the broader features of electrical science of the facts which tell us how to build a dynamo, a motor, and the like. We came to know of strange new forces with mysterious relations between them. But what was their explanation—what was the secret of their mutual relations—of what broad principles of the design of the universe did they form a part? Then came Clerk-Maxwell,

who sought to correlate these discoveries into a more harmonious unity.

Maxwell was a great mathematician; and, as a result of his labors, he wrote a book which few could read, but which, in the years that have followed, has served to mould our thoughts to that comprehension of the subject which we enjoy to-day.

The place of the mathematician, of the dreamer, in natural philosophy, is not always apparent to the layman. He takes the facts which the experimenter gives him, and seeks to correlate them as part of a greater framework of truth in the hope that the frame itself shall suggest other things which may be true, and thus stimulate further search, and widen our comprehension of the whole. A man coming to us from another country, or from another world might, by observing the actions of our President, our Secretary of Labor and the governor of one of our states, form some sort of an opinion as to the probable actions of these individuals under given circumstances. His understanding of the whole situation would, however, be much less complete than it would be were he acquainted with the whole mechanism of our constitution, or even with some part of it which was fairly complete in itself. If his knowledge is confined within the limits we have supposed, however, he might take such information as he had, and try to reduce it to some sort of order by building in his mind a constitution of which such individuals as he knew formed a part. In this creation of his mind, he would have to picture many new individuals and offices in order to complete the framework of his thought. He would naturally suggest a search for these individuals. Every additional one found would add more certainty to his general plan, while every one he failed to find would give him a clue as to how his plan should be modified in order to conform to the facts. When all was complete, or, indeed, long before all was complete, long before he knew the status of every minor clerk in the government's employ, he would be conscious of a much better understanding of the whole situation, and would be in a much better position to draw upon the services of the government than he was when the whole of his knowledge was confined to the actions of the three individuals we named at the start. If this man, who corresponds to our mathematical physicist, should now go back to his own people, he would doubtless have much difficulty in making them under-

stand the plan of our government. The facts they would have to accept, but it might be only after prolonged experience of our actions that the mechanism of our procedure would enter into their inner consciousness with that force which implies understanding.

So, Maxwell sought and found a beautiful scheme of thought in which to comprehend and harmonize the discoveries of his predecessors. The form of his scheme was such as to suggest that it should be possible to propagate electromagnetic disturbances in the form of waves in an all-pervading medium, and that certain of these waves should have the properties of light waves, and that all should travel with a velocity equal to that of light. His conclusions in the latter respects were beautifully verified by his calculation of the correct velocity of light from purely electrical data, and his predictions in the former have received wonderful justification, first in the experimental work of Hertz and Lodge, and finally in the modern developments of wireless telegraphy and telephony in the hands of Marconi and others, developments which at every stage of their progress have drawn upon the principles outlined in Maxwell's great work. We now know that the electromagnetic waves of wireless, heat rays, light rays, the ultra-violet rays used therapeutically, X-rays, the gamma rays emitted by radium and the cosmic rays of which we have heard so much recently, are all special cases of electromagnetic waves differing from each other in their essentials only as regards their length. The longest are the wireless waves, which attain lengths of the order of a mile, and the shortest constitute the cosmic rays, whose length is comparable with the one-millionth of the one-millionth of a centimetre.

And then, following Maxwell, once again science made one of those pauses for breath in which many seem to see the end of all that man may hope to know—those dread pauses in which the horizon of discovery seems the boundary thereof.

Thirty years ago was a time of great depression in physics—a time when would-be Ph.D.'s went about like roaring lions seeking something to measure and finding nothing but the density of a gas or the viscosity of a solid. The sentiment of the times was well voiced by a certain European physicist of eminence who stated that it was probable that all the important experimental discoveries in physics had then been made and that henceforth the

investigator must confine himself to a repetition of what had been already done with greater attention to minor matters of precision.

Even in those days the apparatus cases of most laboratories contained curiously shaped glass tubes containing rarefied gases of various kinds which could be made to glow in fantastic manner by sending an electric discharge through them. Few sought to penetrate the mysteries of those tubes. They would be brought forth on the occasion of popular exhibits in the laboratory, made to go through their alluring performances and then returned to their cases to await the next festivity of the kind. They were not viewed as serious articles of scientific research, but hardly as more than toys. And yet, what a marvellous secret they held! For it was in one of those tubes that, in 1898, J. J. Thomson discovered one of the two fundamental bricks out of which the universe is built—the electron—the tireless worker whose home is in the atom—the thing whose quivers send us light from the sun, whose ceaseless flight around the atom's centre gives the magnet the power to pull—the thing whose motion through the electric cable constitutes the electric current—the thing whose splash when hurled into the atom with great speed is the X-ray—the thing whose motions in the antenna send us wireless waves, and whose motions in the radio tube enable us to detect those waves. It is to the electrons that matter owes all its chemical properties. It is electrons from the sun which are responsible for the aurora. The atoms of which matter is composed are so small that about a hundred million of them laid in line would take up but the length of one-third of an inch, but the electron is so small that even in comparison with the atom it is but as a fly compared with a cathedral. It is so light that if everything were magnified in mass so that the electron attained a mass of four ounces, that four ounces would on the same scale of magnification become as heavy as the earth.

Before the discovery of electrons we had cause to believe that there were such things as atoms and molecules, but nobody ventured to picture their structure, and we felt we had gone far in penetrating nature's mysteries when we were able to say that, on the basis of certain plausible considerations, it was probable that if a drop of water were magnified to the size of the earth, the molecules would become as large as small shot. The discov-

ery of the electron gave a fresh impetus to man's hope of understanding the atom, and before long the second fundamental brick of nature's structure revealed itself—the fundamental unit of positive electricity—the proton, whose natural home is in the nucleus, the heart of the atom. The proton is two thousand times as heavy as the electron but it is two thousand times as small, so that if the proton were magnified to the size of a pinhead, that pinhead would, on the same scale of magnification, attain a diameter equal to the diameter of the earth's orbit around the sun.

At the end of the last century Röntgen discovered X-rays. The property by which they first claimed attention was their power to pass through flesh and so show shadows of the bones of the body. Soon, however, it was realized they were endowed with many other properties of a most important and interesting kind, properties which were bound up with the atom's structure and whose study therefore served to throw further light upon that structure.

Until the end of the last century, one of the most firmly established beliefs was that of the permanence of the atoms. However, near its close, Becquerel found certain curious properties of uranium oxide which suggested that this substance was continually emitting some kind of a radiation which could pass through screens opaque to light, and affect a photographic plate. Several other substances were discovered possessing this property, and many other characteristics of these substances were discovered, characteristics which could only be harmonized on the belief that the atoms of these substances were in a continual state of spontaneous disintegration—of atomic explosions if you will, and that the phenomena observed were the symbols of these explosions.

One may naturally be led to inquire how far discoveries in pure physics and mathematics find their reflections in the things of everyday life in the sense which we call useful. If in a great city we should set out on our travels with the intention of visiting all the places within the field of our immediate interests to the exclusion of others, and if we should refuse to walk along any street which did not itself contain many of these places, then, even as regards those things to which our interest was confined, we should limit greatly the possibilities which that city opened

to us. If this is true of a relatively simple structure like a city, how much more is it true of that beautiful framework of science whose parts are so clearly interwoven that it is almost impossible to touch one of them without producing response in all the others. While, therefore, the man of science must pursue knowledge for its own sake, it is a remarkable fact that practically all of those achievements in the physics of the past twenty years which might be classed as utilitarian, have arisen directly from, or in relation to investigations pursued with no utilitarian motive directly in view. X-rays revealed themselves first in the light of their importance in surgery. The study of their properties shed a new light upon the structure of the atom and this light was reflected back with enhanced intensity to clarify the properties of the X-rays themselves. The immediate application to photographic surgery was obvious, but that field which is concerned with the effects of the rays upon the body tissue, upon the cure of cancer and the like, was not so evident. Bound up as it is with the properties of the rays in relation to their passage through matter, with their absorption in the tissues, and the extent of the molecular disruption which they produce, it must draw for its development upon the more fine-grained aspects of the study of X-rays which the physicist has made in the field of his own interests.

The study of radio-activity has taught us that in the spontaneous disintegration of the atoms which accompanies this process, powerful radiations are emitted. First we have the alpha particle, a positively charged atom of helium, with a velocity of eighteen miles per second. Then we have electrons travelling with a velocity ten times as large and finally we have a very hard type of X-ray known as gamma rays. These rays possess the power to disrupt molecules through which they pass and it is this power which gives them, in common with X-rays, such great value in medicine. The surgeon's knife can dissect the tissues and remove the larger malformations of growth, but the X-rays, the rays from radium, and those of ultra-violet light can dissect the malformation on things ten thousand times smaller than the smallest things which our microscope can reveal.

The detailed investigations of phenomena pertaining to the passage of electricity through gases—phenomena whose study led to the discovery of the electron, necessitated an improvement

in our methods of producing high vacua. The pumps of to-day can accomplish in fifteen seconds what would have taken a couple of hours twenty-five years ago, and the vacua attainable are ten thousand or more times better than they were in those days. We can now reduce the pressure in our apparatus by means of modern pumps to such an extent that only one in every hundred thousand million of the molecules originally present remains. This improvement in the technique of producing high vacua, rendered necessary for investigation in pure science, has rendered possible the electric lamps which we use to-day. It has rendered possible the modern X-ray tube—an instrument not only infinitely more reliable than the weak and capricious tubes of twenty years ago, but controllable in intensity to amounts twenty times as great as those formerly attainable. It is only through the aid of modern vacuum technique that the modern broadcasting station has been rendered possible, that the radio amplifying tube has become a reality, and that we can have wireless transmission of signals, speech and photographs.

If, twenty years ago we had wished to give an example of a type of research which was least likely to have an utilitarian value, we could hardly have chosen a more fitting example than the investigations which Prof. O. W. Richardson had been carrying on in England, and later at Princeton, on the emission of electrons from heated wires; yet it is to these investigations, combined with the power to produce high vacua, that we owe the modern radio tube, the X-ray tube, and a variety of appliances used in the general fields of radio transmission and X-ray technique.

It has long been known that light when falling upon the surface of certain substances possesses the power to eject electrons from them, and the study of this phenomenon has been one of primary importance in relation to our knowledge of atomic processes. But it, too, has had its practical application, for it is this phenomenon which has rendered possible the wireless transmission of pictures, and a variety of other things hardly less important even though less spectacular.

Many years ago, Rowland, of Johns Hopkins University, showed us how to rule very fine closely spaced parallel lines on speculum metal, and use them to analyze light into its component colors. That which the grating does to the light can be predicted

if we know the spacing of the lines; and, conversely, if we had known beforehand the nature of the light, we could have gained information regarding the spacing of the lines. Since X-rays are of the same general nature as light, but of much shorter wavelength, it became a matter of interest to inquire how far such methods could be applied to them. It soon appeared, however, that for the successful pursuit of this problem, it would be necessary to rule lines whose distance apart was of the order of one-hundred-millionth of a centimetre. We cannot, of course, make such ruling, but nature has provided us with something very like them in the regularly spaced atoms which constitute a crystal of rock salt, for example. About fifteen years ago, Laue found that he could make a crystal act in relation to X-rays in very much the same way as Rowland's gratings acted toward light. The matter was pushed rapidly forward by a number of physicists, and soon gave accurate means of measuring the form of distribution, and spacing of the very molecules of the crystals. It is quite impossible in a short space to give any idea of the tremendous field of activity which these discoveries opened up in relation to atomic structure on the one hand, and the nature of X-rays on the other. Not only this, but it soon became realized that there were other fields of usefulness for the new method. Not the least among these has been its application to the structure of metals, which has provided the metallurgical engineer with a new method of attack in the detailed examination of his alloys, and of the effect of strain and other treatment upon them. Whereas formerly the limits to the fineness of his examination were determined by what his microscope could see, he is now almost in a position to look at the very molecules themselves.

Many years ago, Professor Michelson, of the University of Chicago, became interested in the question of whether or not the velocity of light is affected by the earth's motion. This is an experiment having, at first sight, nothing but a philosophical interest. But Professor Michelson obtained an unexpected result, a result which did not harmonize with our understanding of nature's laws; and herein lay its great value, for it showed that our modes of thought required revision. This great revision, not, of course, in the laws themselves, but in the sense in which we interpret them if they are to harmonize throughout, constitutes the theory of relativity—a way of looking at things which

soon made its influence felt outside of the domain in which it was born—a scheme of thought which has enabled us to see harmony in, and so understand, many wonderful things in the theory of electricity, atomic structure, and other branches of physics. Moreover, here again, we meet with a remarkable example of the interdependence of the various parts of science on each other. Of all branches of pure mathematics one could hardly conceive any farther removed from nature than those having to do with non-euclidean geometry, and the so-called absolute calculus of Ricci and Levi-Civita. These were fields so specialized as to be studied only to a very limited extent by mathematicians themselves. Yet, even as an archæologist might suddenly come upon a scroll of papyrus outlining the laws of an ancient civilization, and might therein find the means to harmonize, and understand the other visual records which his search had unearthed, so Einstein found in these abstruse writings of the mathematicians the wherewithal to express the unity of nature's laws in a form so beautiful that he has likened that expression to a wonderful symphony of which our universe is the expression of God's rendering.

Astronomy, the most ancient of the sciences, has always occupied a place in the forefront of the imagination of the scientist and the layman alike. With the motions of the planets coördinated by Kepler, and moulded into a beautiful scheme of physical law by Newton three hundred years ago, there seemed but little more that man could expect to discover. The growth of the science of optics soon provided a tool wherewith to explore farther, however. Laboratory studies of the nature of the light emitted by incandescent solids and gases soon provided a means of determining much concerning the heavenly bodies by a study of the light which they emit. Stars which are so far away that their light, travelling towards us at the rate of 186,000 miles per second, takes thousands of years to reach us, may move with great velocity without that velocity making itself apparent by direct observation. A study of their light has enabled us to determine their speed in very much the same way that we could determine the speed of a train by noting how much the pitch of its whistle is altered by the motion.

The stars are so far away that even in our most powerful telescopes they appear but as points in spite of their great size;

but by drawing in greater detail upon our knowledge of the way in which light comes to us and of the effect of the size of the emitting body on the character of the light, Professor Michelson, at an age when most men are content to rest upon their laurels, performed one of the most brilliant feats of a lifetime of masterly achievements in measuring the diameter of one of these stars, a feat equivalent to measuring the diameter of a penny at a distance of a thousand miles.

Strange as it may seem that we can learn so much about the stars which are so far away, the last few years has enhanced still further the wonder of it all. For the knowledge which we have gained about matter by experiment in the laboratory has found a most remarkable field of application in enabling us to understand the conditions which must prevail in the stars; and, these stars by their peculiar characteristics of large size, high temperature, high density, and so forth, have provided us with conditions to test our conclusions such as we could never have hoped to attain in the laboratory. A gas compressed to a density eight thousand times that of steel is but a figment of the imagination in the laboratory, yet of such stuff is the Companion of Sirius made. Temperatures of forty million degrees correspond to things ten thousand times as hot as any temperatures we find on earth, yet nature has realized such temperatures in some of the stars. And so the stars, far from being things through which we dare hope to learn but little have, by their exceptional condition, served to provide us not only with a very fascinating story of their own life history, but with a large part of the story of the birth of matter itself.

Discoveries in the fields of experimental science naturally go hand in hand with that study of the laws of design of the universe which we call theoretical science. One supplements the other, and the strength of one enhances the strength of the other. It is naturally around the atom's structure that the thoughts of men have loved to hover. And here, the power to comprehend a new point of view has grown enormously in the last few years. We have a clearer understanding of what understanding means. We were in danger of becoming so enamoured of those laws which govern the behavior of matter in bulk as to refuse to admit any other possibilities in respect to the laws of the atom. The workings of the coarse-grained things of nature were all

about us. Pulleys, springs, water torrents, the waves of the sea, these were things of common experience, and the mind sought contentment in the thought that the atom might utilize in its structure only things which behaved as these things behaved; and even as a little hill may hide the Alps from one whose life is in its shadow, so there was danger in the known and obvious workings of the common things around us obscuring from our vision the story of that great universe of the atom which lies beyond. Happily, the complacency of our outlook has received, in recent years, one or two serious jolts. First came the theory of relativity, which taught us that a greater elasticity of thought was necessary if we were to understand nature as she is rather than as we might have made her. Then came a series of experimental phenomena which seemed to violate all our notions of how things should be, and since we could not alter the experimental phenomena we had to alter the notions, and so there arose the so-called quantum theory of atomic structure—one of the most helpful crystallizations of thought for correlating the facts that we have ever had. And then, as further search showed this theory to be inadequate beyond a certain stage, there arose only a couple of years ago, an entirely new way of regarding the atom —a way so radical in its point of view that it is safe to say that had it been put forward fifteen years ago, it would hardly have attained a hearing. Born in a day of more liberal thought, however, it had no sooner made an appearance than a host of workers arose to welcome it and to develop it consequences, so that to-day there is hardly a physical laboratory in the country which does not contain one or more people who have acquired the power to think in its terms.

In speaking of theories being discarded and superseded by others, we must not think of the discarded ones as useless. The situation is not so much one where we are to think of a certain theory as right and all the others wrong. In a sense, different theories are like different languages for describing the same phenomena. The English language may be more suitable—more powerful for the purposes of the science of chemistry than the French language. It may have a greater richness of word content; but to say that one is right and the other wrong is to utter nonsense.

And so, a quarter of a century after the prediction of the

eminent European philosopher to the effect that discovery was ended we find ourselves in the most intensive period of scientific activity of all time. We may well ask where we are headed. Shall we continue to discover new treasures, or, when we have catalogued those we have, shall we reach again one of those periods of stagnation? If we do, and if there be any one who then feels that progress is ended, that knowledge is complete—and that science is dead, let him think of how confidently he could have voiced that same thought in the civilization of the Pharaohs. Let him think with what surety he would have voiced it in the years which followed Newton. Let him think how he would have voiced it—yes, perhaps how he did voice it thirty years ago, and then let him take hope. For, the words of the Bard of Avon are truthful yet. There is more in heaven and earth than is dreamed of in even twentieth century philosophy, and the richness of nature's content will not be fathomed in our time.

THE DESIGN, CONSTRUCTION, AND EQUIPMENT OF THE BROAD STREET SUBWAY IN PHILADELPHIA.*

BY

HENRY E. EHLERS.

Director of City Transit, Philadelphia.

THE TRANSIT SITUATION IN PHILADELPHIA AND ITS DEVELOPMENT.

The Period 1912–1923.—The City of Philadelphia many years ago reached a point in its development where it was recognized that it must have high-speed transit service and that the city itself would have to undertake at least the burden of construction, with the belief that the best results could be secured only by the operation of the city-built lines and the privately-owned lines as a unified system. In 1913 legislation was passed conferring on the city the right to purchase, lease or construct transit facilities and to own, lease or operate such facilities, and adding to the city government a Department of City Transit.

A system of rapid transit lines (The Taylor Plan) was adopted, funds authorized, and construction work started on the section of the Broad Street subway under City Hall, on sections of a delivery loop in Arch and Locust Streets, and on the Frankford elevated line. Federal restrictions arising from war conditions made necessary the cancellation of certain contracts and a limitation of the work under construction and prevented further advance in carrying out the program. The construction work under City Hall was completed, the now abandoned sections in Arch and Locust Streets were closed up, and the Frankford elevated line was completed and put in public service late in 1922. Changing conditions and viewpoints during this period led to a demand for a revision in the routes, and after consideration of the situation by a Councilmanic Transit Commission, a material revision in the general plans and program was authorized by the voters in the fall election of 1923.

The Department of City Transit is one of eight departments under the mayor. It has no regulatory power over the rates, service or facilities of the existing privately-owned transportation

* Presented at a meeting held Thursday, December 1, 1927.

system. Its principal functions are to plan, design and construct transit facilities as authorized and directed by City Council, and to study transit needs and developments and related problems. The preparation of plans and specifications, the receipt of bids, and the awarding of contracts, and the supervision of construction are its direct responsibility.

The Philadelphia Rapid Transit Company operates as a unified system an extensive street railway system, a rapidly growing bus system, a taxicab company, and the Market Street subway-elevated line which connects the eastern and western portals of the city with the central business section and the rapidly developing areas in the northeast. The Frankford elevated line is owned by the city and leased to the Philadelphia Rapid Transit Company. The rest of the existing system is privately owned.

The main features of the program adopted in 1923 are shown on Fig. 1. For immediate construction this program called for the building of a subway in Broad Street, of four-track capacity from Spruce Street to Olney Avenue, with a two-track branch under Ridge Avenue from Broad to Eighth Street, thence along Eighth Street to Walnut Street, westwardly in Walnut Street, crossing the Schuylkill River to West Philadelphia, and connecting at Forty-second Street and Woodland Avenue with an elevated railway leading to Darby. The Broad Street subway and the branch to West Philadelphia will form the backbone of a transportation system by directly connecting the rapidly increasing population in the northern part of the city with the industrial and residential sections to the southwest, with provision for through-routing and for delivery in the central business and commercial districts.

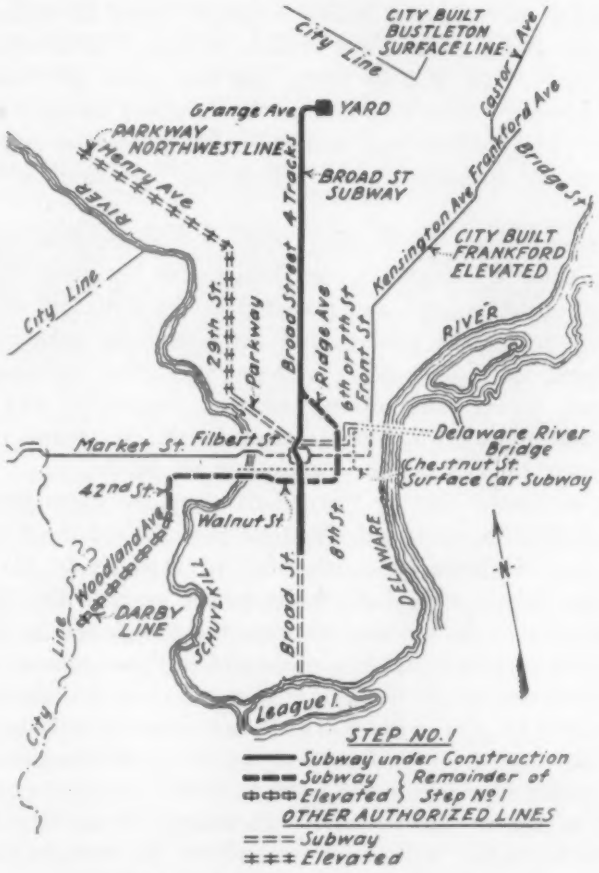
The early construction of a surface car subway in Chestnut Street between the rivers for the relief of street conditions in Chestnut and Walnut Streets by the removal of the surface railways, and for the improvement of east and west street railway service through the business district, was another item in this program, on which construction work has not yet been started.

The Period 1924–1928.—With the beginning of Mayor Kendrick's administration in January, 1924, work was started on the assembling of a staff and the preparation of contract plans for subway construction, it having been determined to concentrate

efforts on the portion of the subway in Broad Street, with a goal of initial operation by the end of 1927.

The attainment of this goal, or its near attainment, involved performances very far beyond anything heretofore accomplished

FIG. 1.



Rapid transit system authorized in 1923.

in similar fields. It involved not only the design and construction of the four-track tube itself, but also the much more complex problems of designing, specifying and providing all of the equipment required to make up a subway railway complete in all

features, including track, cars, shops, power substations, power distribution system, signals, etc.

The construction plans prepared in earlier years for other routings and other station locations were no longer applicable. Alignments, profiles, station locations, clearances, etc., had to be determined to meet the new conditions and new construction plans had to be prepared before contracts could be placed. On August 25, 1924, ground was broken in Broad Street under the first contract. In March, 1927, the 6½ miles of four-track subway structure from City Hall to the yard and the yard grading and shop foundations had been completed, surface restoration work was far advanced, and track laying operations were well under way.

In addition to supervising subway construction contracts totalling some $58,000,000, the department designed, prepared plans and specifications, and placed fifty-six contracts for other structures, permanent paving, and for equipment such as track, cars, signal and interlocking system, substation buildings and equipment, power-distribution facilities, inspection and repair shops, administration building, station finish, etc., going to make up a subway railway system complete in all details.

It is estimated that by the end of 1927 the expenditures on this work will have totalled about 92 per cent. of the total estimated cost of the work north of City Hall ready for initial operation. The completion of the power system, the finishing and equipping of the subway stations, the completion and testing of cars, the provision of shop tools and equipment, and the trying out and tuning up of the system as a whole are the controlling elements in getting the North Broad Street subway ready for public use, and from present indications such completion will require about four months in 1928.

The section of the Broad Street subway from City Hall to South Street, which will add very much to the Broad Street line by improved delivery service, improved terminal conditions, and relief of the City Hall Station, was placed under contract in August, 1927, and is now actively under construction.

The estimated cost of constructing the Broad Street subway and equipping it for operation between South Street and Olney Avenue on a two-track basis is practically $100,000,000.

THE BROAD STREET LINE AND THE SUBWAY STRUCTURE.

Some General Considerations and Their Application.—A four-track subway under city streets is a very costly right-of-way. The greater the number of people that can be carried through it in comfort and safety, the greater the potential benefit to the public in return for the expenditures made for tube and equipment. Station locations and arrangements making for easy and rapid movements to and from trains; car seating and door arrangements and equipment making for rapid loading and unloading; alignment, profile and track arrangements, signals and other safety devices, car motors and brakes and couplers, terminal and yard connections, etc., making for frequency, rapidity and safety of train and car movements, are all features which have been planned and designed with the above principle in view.

While some of these features can be modified from time to time as conditions change and the art progresses, material changes in those which affect the main subway structure are practically precluded by reasons of cost as well as interference with use. The design must therefore make provision, not only for the near future, but must also envisage as far as possible the requirements and developments of a distant future. Alignment, profile, stations, track arrangement, and terminal facilities fall within the latter group.

Considerations of this general nature supported the decision of the city in 1923 to make the Broad Street subway a four-track line to Olney Avenue, and guided the department in its designs, as for example, in the extensive construction north of Olney Avenue, in the yard connection under Grange Avenue, and in the layout of the yard and shops. Branches to the northeast and northwest are authorized, but not definitely located. In the structure as built, extra track spaces have been provided to a little beyond Grange Avenue for the extension of either or both pairs of tracks northward at any time, without disturbance of the existing structure or of the operation of trains therein, and of course without any grade-crossing movements.

The Olney Avenue Station is the present northern terminal of the line, and with the Grange Avenue yard connection just north of it, it was necessary to provide for the greatest possible freedom of car and train movements incident to terminal operations. The ultimate capacity of the subway will be largely fixed

by the number of trains that can be moved through this section. Extended investigation was made of many general plans, including double-deck and single-deck stations at Olney Avenue, two-platform and three-platform single-deck stations, six-track double-deck and three- and four-track single-deck yard connections under Grange Avenue, etc. The plan finally adopted consists of a two-platform single-deck station at Olney Avenue, a four-track single-deck yard connection with complete separation of grades, and the extension features noted above, and is considered to provide adequately not only for operation in the earlier years, but also for operations extended to the north and on the basis of the maximum capacity of a four-track tube.

Just north of the Erie Avenue Station, where the subway profile is dropping to get under the Reading Company's tracks, advantage was taken of the situation to provide a two-level structure, whereby local trains can be turned back at this point without grade-crossing movements. This provision will enable a balancing of service and traffic and added flexibility of operation.

The two-track branch to Ridge Avenue has been provided for by a special six-track two-level construction enabling either express or local service to be diverted into Ridge Avenue, and with a complete separation of grades. The location of the Fairmount Avenue Station at this intersection added to the size and complication of the resulting structure.

Profile and Alignment.—The distance from City Hall to Olney Avenue is six miles, and in this distance there is a total rise in elevation of top of rail of 167½ feet. The maximum main line grade is 3 per cent. and the minimum centre line radius on main track is 200 feet. The maximum grade of the track in station areas is .3 of 1 per cent. The equipment has been designed so that the running time between these points will be about twenty-two minutes for local service, and about seventeen minutes for express service.

The profile has been kept as near the surface as conditions would permit, in order to save cost and to add to public convenience. Some controlling points which forced the profile down are at Walnut Street, Chestnut Street, City Hall and Filbert Street, where the Broad Street subway must pass under existing or authorized lines, and near Callowhill Street, Lehigh Avenue,

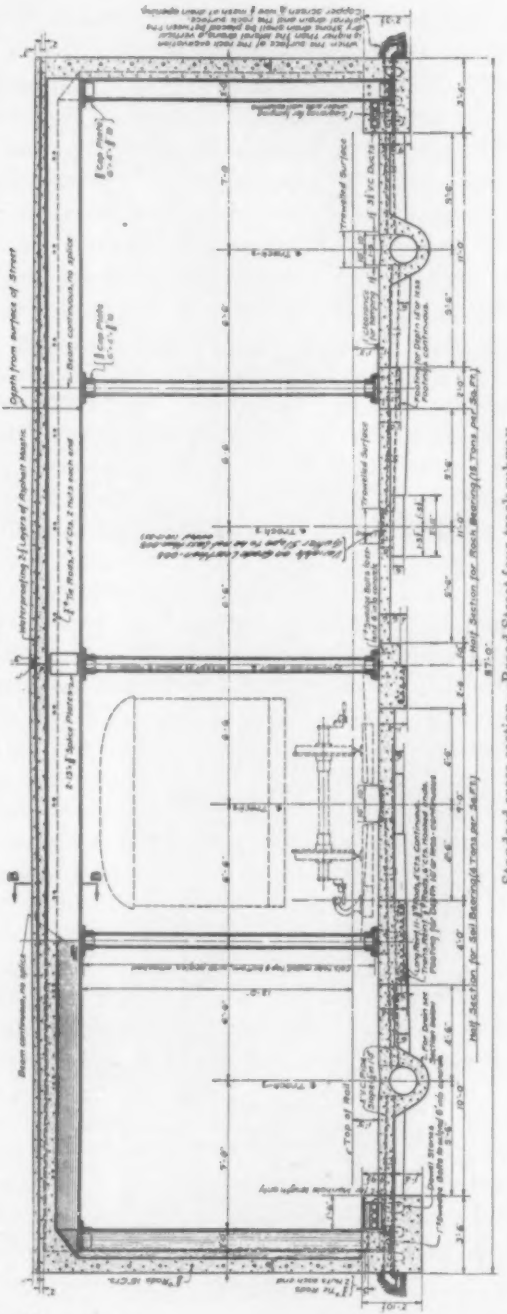


FIG. 2.

Standard cross-section—Broad Street four-track subway.

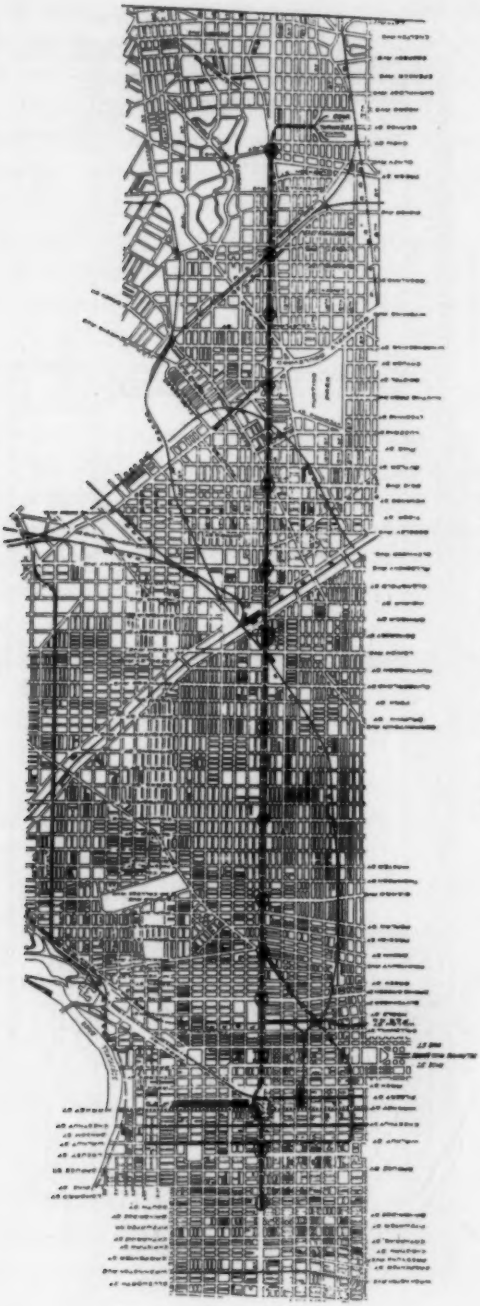


FIG. 3.

Station locations—Broad Street subway.

and Lycoming Street, where the subway must pass under railroads, which in turn cross Broad Street below grade.

At Thompson, Dauphin, York and Clearfield Streets, and at Belfield Avenue, it was just possible to create space enough below the paving base to pass the subway structure over large intersecting sewers by extensive sewer reconstruction and some relocation. Rectangular sewer sections were used at the crossings, the floor of the subway forming the roof of the sewer. At Belfield Avenue, where provision was made for a 14-foot sewer and a 16-foot sewer, ultimately to cross Broad Street at this point, the roof of the subway is practically the paving base, and all north and south underground structures must be located in the east or west shoulders of Broad Street until past this restriction.

Standard Cross-section.—Broad Street is 69 feet between curbs and 113 feet between house lines. The overall width of the four-track structure is 57 feet at standard sections, widening out to 113 feet at and near stations. As shown in Fig. 2, the structure has a concrete invert, steel columns and roof beams spaced 5 feet 6 inches, with concrete jack arches forming the side walls and roof. The standard vertical clearance over the top of rail is 13 feet and the spacing of track centres is 13 feet. Subway clearances have been provided on the basis of cars 67½ feet long, 10 feet wide, and 12 feet 3 inches high. Waterproofing, in general, has been restricted to the roof, where two ½-inch layers of asphalt mastic form a membrane protected by a 3-inch coating of lean concrete. Lateral drains are provided at frequent intervals to reduce accumulation of water along the subway walls, and longitudinal drains under the track carry all water to float-controlled electrically operated pumps installed at the five low points on the line. A duct bench along the outer wall forms a walk and together with the extra clearance afforded by the side-wall arches, offers a safety zone for trackman and others working in the tube during operation. The main duct runs for power lines and other uses are outside of the subway, and in general on the subway roof.

Subway Stations.—There will be sixteen stations along Broad Street; two south, and thirteen north, of the City Hall Station; the average spacing outside of the delivery district being about one-half mile. The locations and spacings are shown on Fig. 3. Their determination involved a balancing of factors such

FIG. 4.

Erie Avenue Station—plan and sections.

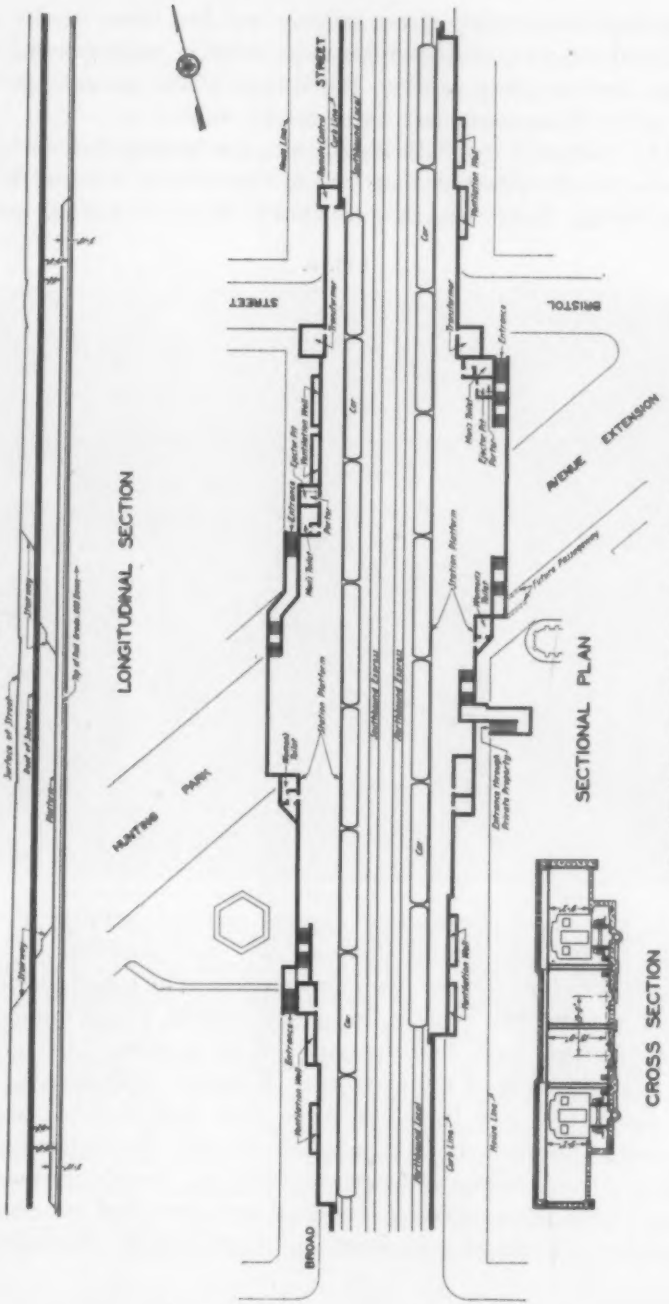


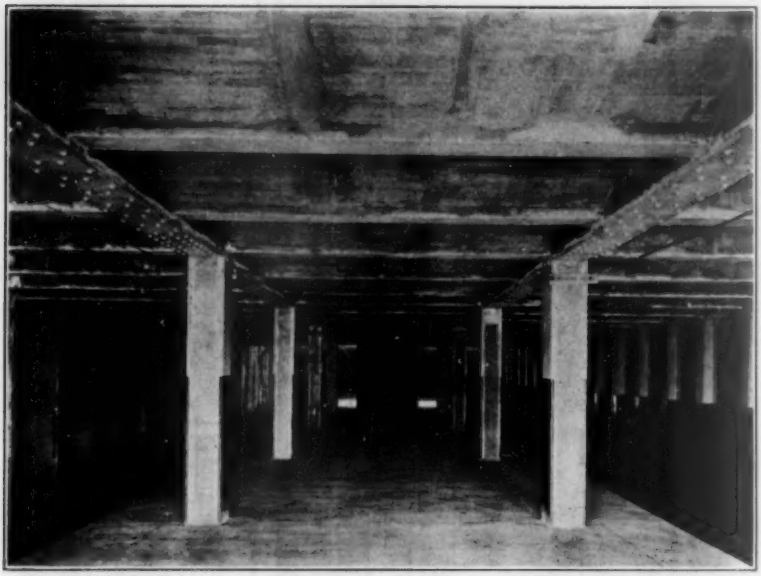
FIG. 5.

Hunting Park Avenue Station—plan and sections.

as spacing, intersecting street railway and bus lines, nearby railroad stations, local traffic or business centres, underground conditions, and resulting profile. All station platforms are 550 feet long and will accommodate an eight-car train.

The Walnut, City Hall, Race-Vine, and Spring Garden Street Stations in the delivery district, and the Girard Avenue, North Philadelphia, Erie Avenue and Olney Avenue Stations to the

FIG. 6.



Island platform—Lehigh Avenue-Glenwood Avenue (express) Station.

north, are island-platform or express stations, serving all four tracks. The intervening stations are side-platform or local stations, serving only the two outer tracks. The island platforms, except at City Hall Station, have clear widths in the middle sections of about 20½ feet, tapering off to between 13½ and 18 feet near the ends of the platform. Frequent stairways, averaging about 5½ feet in width, have been provided to facilitate movement between the station platform and the mezzanine and particularly to reduce movements along the length of the platform. Liberal mezzanine areas have been provided for ease and flexibility of control and freedom of movement of traffic, for

operating rooms and for adequate toilet rooms and similar conveniences for the public and for the operating staff. At important crosstown streets, where the profile is high and brings the roof of the mezzanine rather close to the surface, as at Erie Avenue, the mezzanine has been separated into two parts, in order to furnish liberal provision between them for future crossing of Broad Street at such points by major city or public utility structures.

The width of side platforms varies from a minimum of 10

FIG. 7.

Side platform—Dauphin Street-Susquehanna Avenue (local) Station.

feet for short sections near the ends of the platform, to from 30 feet to 40 feet in the middle sections. The clear height from floor to the bottom of roof beams is in general about 8 feet for mezzanine, passageways and stair entrances, and 9 feet over platform areas. Street entrance stairs vary in width and number per station, but in general are not less than 6 feet wide, are located in the sidewalk against the house line, and will be uncovered. In a number of instances, through coöperation of building owners, entrances have been secured through private property—back of the house line—thereby reducing encroachment on sidewalk areas and any resulting congestion of traffic.

In order to help secure brightness and cheerfulness in the subway stations, and to promote cleanliness and permanence of appearance, the side walls of entrance stair wells, passageways, mezzanines and side-platform stations will be finished in white tile, with colored tile borders and station name panels. The color scheme and pattern repeats every fifth station, and will quickly be quite an aid to the regular rider in locating his station. Ceil-

FIG. 8.

Sketch of station wall tiling.

ings and subway side walls opposite island-platform stations are to be rubbed smooth and painted in a light color.

Typical layouts of platforms, mezzanines, entrances, etc., are shown in Figs. 4 and 5, and typical platform views in Figs. 6 and 7. A sketch of station wall tiling appears in Fig. 8.

Railroads and Other Station Connections.—The North Philadelphia subway station is centred on Somerset Street, with stairways at Lehigh Avenue, Somerset Street and Glenwood Avenue. A passageway 12 feet 6 inches wide, built on the subway roof, connects its north mezzanine with a passageway built by the Pennsylvania Railroad, leading directly to its North Philadelphia

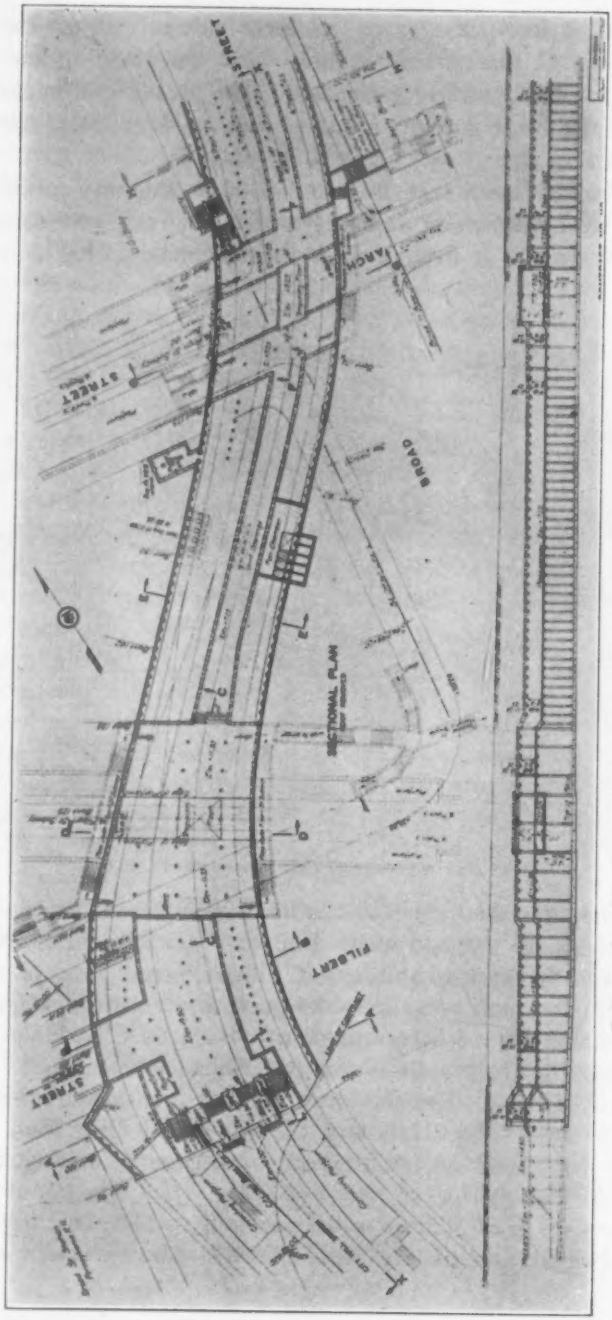


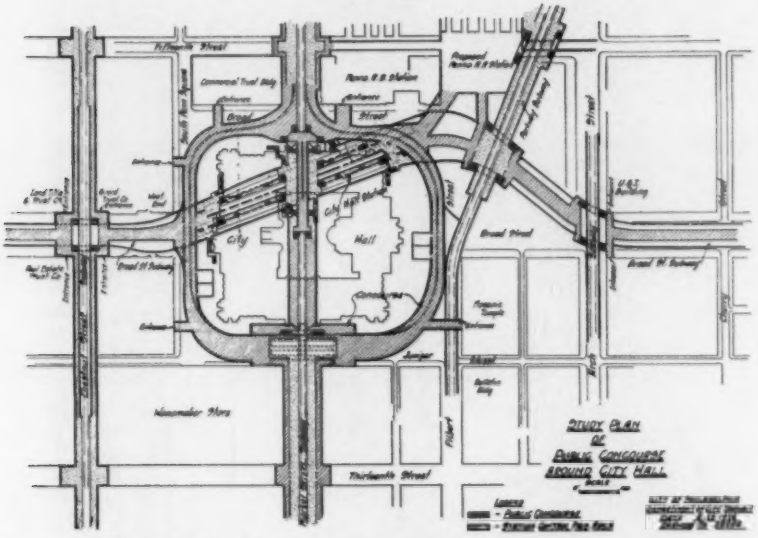
FIG. 9.

Subway plan, City Hall to Arch Street, showing connecting passage and mezzanines.

Station. A like passageway has been built to connect the south mezzanine of the subway station with the Huntingdon Street Station of the Reading Company. The Reading Company has planned the construction of a new four-track railroad station at this point.

A similarly constructed 14-foot wide passageway connects the Race Street mezzanine and intermediate subway entrances with mezzanine areas at Filbert Street, which in turn give a new and

FIG. 10.



Study plan of underground concourse around City Hall.

direct access to the City Hall Station of the Broad Street subway, the proposed Pennsylvania Railroad underground electrical suburban station, the authorized Filbert Street subway station, etc. This mezzanine area is designed and constructed so as to enable underground access to points south of City Hall, and to the Market Street subway of the Philadelphia Rapid Transit Company, if and when the latter subway line is carried straight through under City Hall and the suggested City Hall underground concourse is constructed. Its general arrangement is shown in Fig. 9.

The City Hall Station and Concourse.—The structure of the City Hall Station of the Broad Street subway was completed

some years ago. The existing entrances, with the exception of the recently constructed connection to the Filbert Street mezzanine just described, are all on the City Hall Plaza or in the courtyard, which means that all traffic to and from this station will have to cross the traffic flowing in the streets surrounding City Hall. This situation was caused by the lack of sufficient head room over the P. R. T. subway structures surrounding City Hall to permit the construction of underground passages leading to entrances on the far side of the streets involved.

Following publication in the daily press early in 1924 of a proposal for an extensive system of underground concourses in the centre of the city, the Department of City Transit made a new study of the subsurface conditions surrounding City Hall and in a report to the mayor, which was published in May, 1924, presented a study plan of a solution (Fig. 10) and its advantages, general requirements and approximate cost. Briefly summarized, the report and plan provided for a concourse completely encircling City Hall and extending in Broad Street beyond Chestnut and Arch Streets, forming a direct underground connection between all of the existing and proposed subway and railroad stations in the general vicinity of City Hall, with entrances and exits through or convenient to large office buildings, etc. Such a concourse would aid materially in spreading and distributing underground traffic to and from the various existing and proposed railroad and subway stations in this section, thereby relieving the surface of a large portion of this traffic, and would also improve materially the accessibility of the City Hall Station of the Broad Street subway.

It was proposed to utilize for the section of the concourse encircling City Hall the structure now occupied by the subway loop of the Philadelphia Rapid Transit Company, except that on the Juniper Street side the concourse was planned to be in large part new construction over the present surface-subway line and station. The section in Broad Street consisted of passageways over the roof of the Broad Street subway. The project would involve both the city and the Philadelphia Rapid Transit Company, as it would require extensive rearrangement of P. R. T. structures around City Hall and reconstruction in City Hall basement.

The principal requirements are:

That the P. R. T. Market Street subway rapid transit tracks be carried straight through under City Hall instead of looping around City Hall as at present.

That the P. R. T. surface-subway loop tracks be depressed from a point west of Fifteenth Street Station to approximately Juniper Street, passing under the Broad Street subway at the north and south intersections, instead of over it as at present.

The straightening of the Market Street subway high-speed tracks would improve the service by decreasing the running time and would materially improve the operating conditions at this point. It would also permit the lengthening of the platforms of Thirteenth Street and Fifteenth Street Stations and increasing the width of the Fifteenth Street Station platforms. In addition to this, the changing of the subway-surface loop would give an opportunity to improve and enlarge the important station at Juniper Street. The principal drawback to the materialization of this project has undoubtedly been the large amount of construction or reconstruction which it involves and the consequent high cost, which was then estimated as approximately $6,000,000. The plan was received with much interest and approval, but has never been formally adopted. Nevertheless, the plans for the Broad Street subway have been made to conform with the general plan of the City Hall concourse and in some instances have anticipated certain of its features, both north and south of City Hall.

A double crossover has been installed just north of City Hall Station to enable its use as a stub-end terminal until such time as the section to South Street is ready for operation. Initial operation ending at City Hall will impose traffic which will tax heavily the capacity of the existing platforms and internal stairs, etc., of City Hall Station. Modifications to mezzanine areas and connecting stairs, the widening and extension northward of the station platforms, their connection by large stairways to the mezzanine area north of Filbert Street, and certain temporary stairs and platforms at the south end of the station have been made or are to be made under a station finish contract now advertised, and in our opinion will enable the expected traffic to be handled.

The Walnut Street Station and Concourse.—A distinctive feature of the subway section now under construction south of City Hall is the provision of a mezzanine extending over the full

width of the subway structure from South Penn Square to practically Spruce Street, as shown on Fig. 11.

When placed in operation, the station between Walnut and Locust Streets will undoubtedly handle a very heavy traffic and will then materially relieve the heavy traffic which City Hall Station will have to carry during the period of its use as a temporary terminal during initial operation. The great importance of this station has been recognized and advantage taken of every opportunity to provide a facility of maximum capacity and convenience. The importance of easy communication between the station areas of the Broad Street line and of the authorized Chestnut Street and Walnut Street lines which cross over it, and between the mezzanine area in Broad Street and the proposed low-level sidewalk in Chestnut Street, and between mezzanine and street through buildings, etc., were important factors recognized in developing our plans. Our design sought large capacity, ease and flexibility of traffic movements under ground, maximum number of entrances and exits through private property and flexibility in their location—to the greatest extent consistent with reasonable subway depths, profiles, provision for underground structures, suitable fare control areas, and resulting costs.

As indicated above, the mezzanine area will be intersected at Walnut and at Chestnut Streets by the authorized east and west subways, and after the construction of these lines it will be necessary for persons desiring to move underground past these intersections to use stairways and underpassages of ample width located on either side of Broad Street just outside of the main subway walls.

The project of providing a continuous passage unbroken at intersections by lowering the Broad Street subway and also the Chestnut and Walnut Street subways, as well as a project for a partial lowering of these lines to provide for overpassages at the intersections, was the subject of extended investigation and study by the department. Both schemes, in addition to involving added costs running into the millions, involved sacrifices of very desirable elements such as one-level connections and ample control areas at Walnut and Chestnut Streets, not to mention practical defeat of the scheme of continuous sidewalk platforms in Chestnut Street for some distance either side of Broad Street.

The plan adopted places the Broad Street mezzanine at Walnut

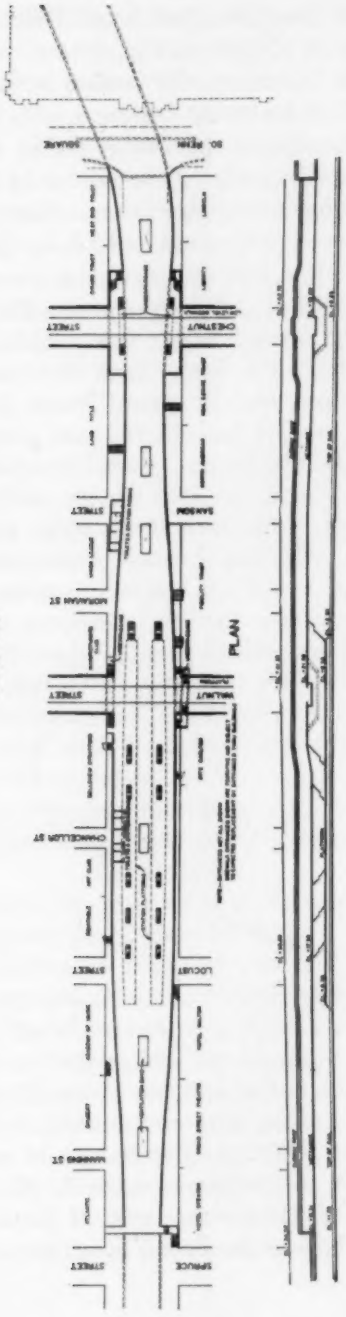


FIG. 11.

Subway plan, City Hall to Spruce Street, showing station and mezzanine arrangement.

Street at the platform level of the Walnut Street line, and at Chestnut Street at the level of the proposed sidewalks, and at South Penn Square at the level of the proposed City Hall Concourse. The side walls of the mezzanine have been planned to facilitate the construction of entrances through adjoining buildings instead of through the sidewalk area, as well as the development, where conditions are favorable, of store entrances and show windows in the side walls of the mezzanine. The commercial development of space in the mezzanine is a matter of the future. Much interest has been expressed by property owners in this section in this feature of our plans and tentative agreements have been made covering a number of entrances through adjoining buildings.

We are convinced that as designed, the subway south of City Hall will render the maximum all-around convenience to the public, including material relief of surface conditions, and of expected congestion at City Hall Station of the Broad Street subway, and will fit in with and furnish further relief in connection with the City Hall Concourse scheme if the city decides to construct it. City Hall Station will be further relieved when the authorized Ridge Avenue-Eighth Street branch is completed and put into service.

Ventilation of the Subway.—The comfort and, at times, the safety of the riding public demand an adequate and effective system of ventilating the subway. There must be air movements enough to maintain the " freshness " of the air in the subway to prevent excessive temperature rises during the summer months, and in case of smoke-producing accidents in the subway quickly to carry away the smoke in order to minimize panic conditions and other dangers due to lack of visibility.

The widest experience in the solution of the ventilation problem for high-level subways similar to Broad Street has been in connection with the development of the subway system in New York, and as in many other matters, the department naturally first turned to this source of information in starting its investigation and studies. Observations were made from time to time of air conditions in different sections reflecting the progressive development of New York practice and design, and data collected as to theory and practice and experience elsewhere in the solution of similar ventilating problems.

It was determined to rely upon natural ventilation, aided by the piston action of the trains, through sidewalk gratings of ample capacity, and in the deeper sections of the subway near City Hall to provide fan chambers so that if in later years it becomes necessary, the natural ventilation can be supplemented by mechanical ventilation. The provision of a diaphragm wall between the two middle tracks, for the purpose of increasing the

FIG. 12.

Typical ventilation wells under construction.

piston action of the trains, was considered and the conclusion reached that it would not be needed for many years, with considerable doubt as to its ultimate necessity. If and when needed, it can readily be built.

Ventilation wells are provided of reinforced concrete construction, connecting openings in the side wall of the subway with sidewalk gratings located at the curb. A typical construction is shown in Fig. 12. The grating units are 4 feet wide and 5 feet long, arranged in banks of from three to six units, distributed as uniformly as underground and surface conditions would permit, and to the extent practicable with openings at all summits

and valleys. The grating area provided is in proportion to the air content of the subway structure, which varies from about 740 cu. ft. per foot of length between stations, to about 1030 cu. ft. at local stations, and to about 1250 cu. ft. at express stations.

FIG. 13.

Ventilation well equipped as emergency exit.

At and near station areas, 1 sq. ft. of net ventilation area was provided for every 750 cu. ft. of subway contents. This is in addition to the entrance stair openings. Between stations, the design was based on a ratio of 1 sq. ft. net area per 1000 cu. ft.

of subway contents. Between City Hall Station and Grange Avenue, there is an average of sixteen units in each side per square. Observations in the tube during the past year or so indicate very considerable air movements, and support our expectations of unusually satisfactory air conditions in the subway.

Ventilation openings at station platforms will be screened and fitted with louvers to prevent snow drift and street dirt, etc., from blowing through to the discomfort of passengers. On either side of the subway and about half-way between all stations, a modified ventilation well (Fig. 13) is equipped with stairs and a counterbalanced grating at the sidewalk so as to serve as an exit from the track level for passengers or as an entrance for rescue forces in case of emergency. The location of these exits will be indicated in the subway by lighted signs connected with the subway lighting system, which is on duplicate circuits with automatic throwover devices to guard against failure of one circuit. A fire alarm and telephone will be located at each emergency exit.

CONSTRUCTION OF THE SUBWAY.

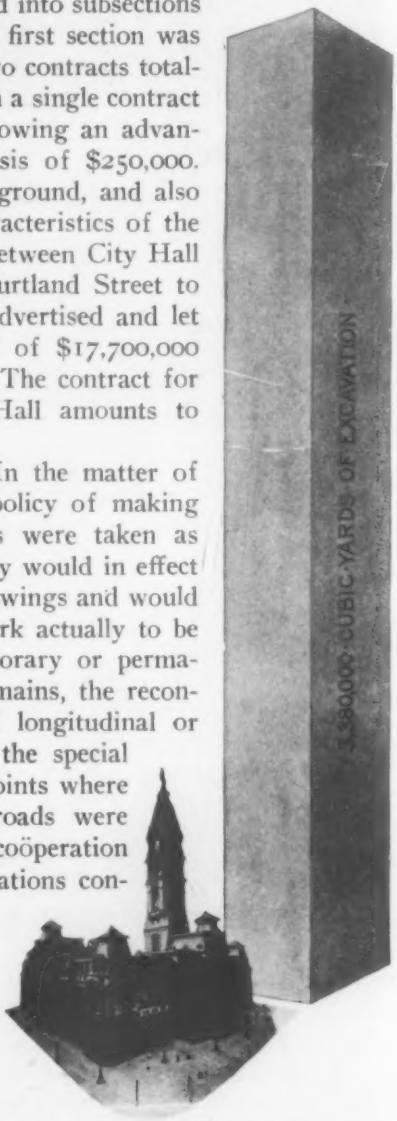
General.—The general methods and practices which enabled the completion of 6½ miles of four-track subway structure in considerably less than three years from the time of breaking ground under the first contract, and the conditions encountered and special features of design and construction, can only be outlined in this presentation.

This rapid completion of the tube has been a decided factor in reducing the total time required to complete and equip the line for initial operation. The size of the contracts, the completeness of the bidding plans and specifications, the methods employed by the contractors, the speed and skill with which the work was carried on and completed well within the specified time, the provisions for minimizing the interference of construction with street use, and the work as a whole were the subject of widespread interest and favorable comment by outside contractors, engineers and municipal officials. Many of the methods and practices developed here are now being employed elsewhere.

Size of Contracts.—The many advantages of dividing the work into large sections, such as attracting the ablest and most experienced contracting firms as bidders and obtaining lower costs due to larger operations, were recognized, as was also the

fact that the size of the contracts might restrict the extent of competition in the bids. Proposals on the first and second sections were requested on alternate bases, the work as a whole, and the work divided into subsections about 5000 feet in length. The first section was awarded to one contractor in two contracts totalling $15,300,000. The second in a single contract of $14,300,000, the bidding showing an advantage on the single contract basis of $250,000. With this experience as a background, and also because of certain physical characteristics of the work, the remaining sections, between City Hall and Stiles Street and from Courtland Street to and including the yard, were advertised and let as single contracts with limits of $17,700,000 and $12,300,000, respectively. The contract for the structure south of City Hall amounts to $8,100,000.

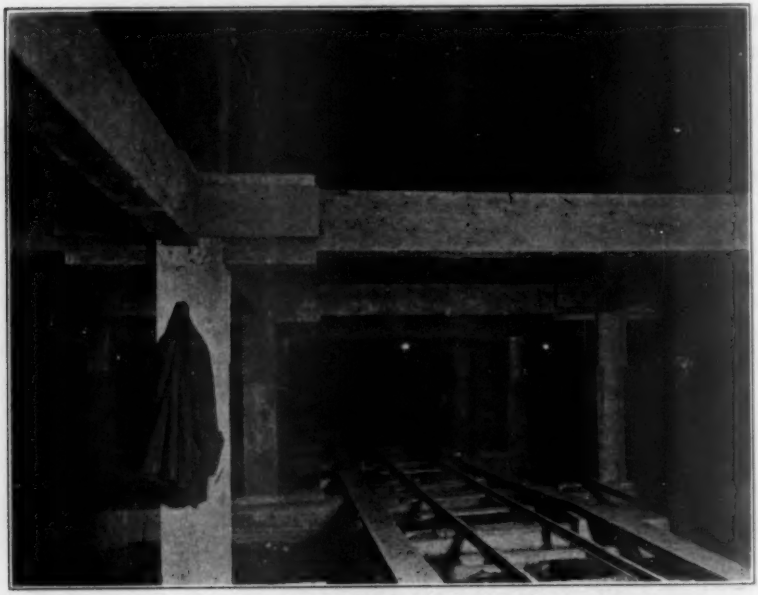
FIG. 14.



Earth and rock excavation—subway north of Spruce Street and terminal yard.

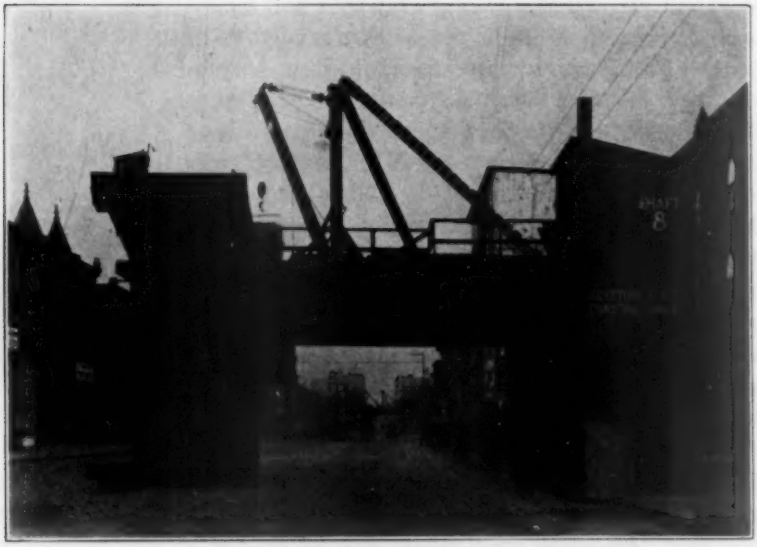
Plans and Specifications.—In the matter of plans, we determined upon a policy of making the drawings upon which bids were taken as complete as possible, so that they would in effect represent the actual working drawings and would portray correspondingly the work actually to be done. Provision for the temporary or permanent relocation of large water mains, the reconstruction, where necessary, of longitudinal or large intersecting sewers, and the special construction required at three points where the subway passed under railroads were worked out in detail and in coöperation with the departments or corporations concerned and embodied in the plans and included in the construction contracts. The steel drawings were detailed to such an extent as to enable the subcontractors for this work to make an immediate start on the shop drawings and then

FIG. 15.



Cross-bracing and post method of timbering—Keystone.

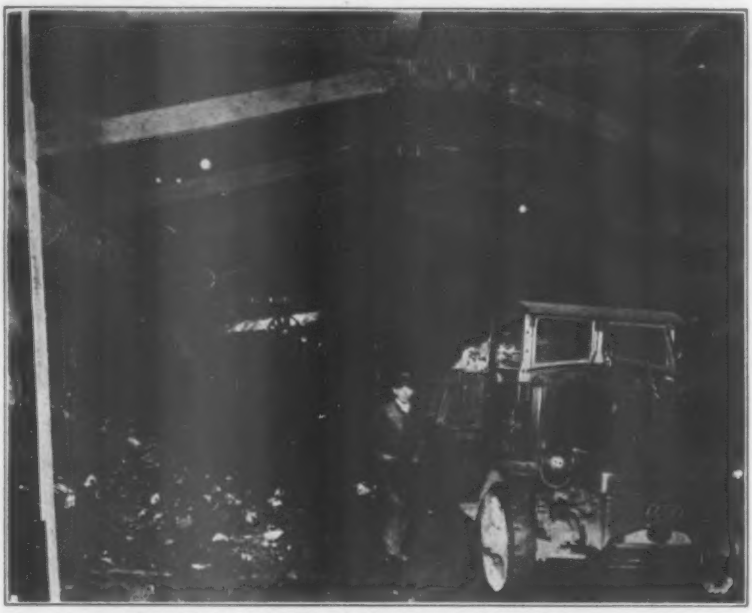
FIG. 16.



Typical shaft—Keystone.

the fabrication. The plans and specifications set forth fully the provisions to be made to take care of traffic and the limitations and otherwise in the matter of ramps, derrick structures, etc., necessary for construction purposes. Of course in the progress of the work some changes in the plans always become necessary, but we are convinced that the extra time and effort required to present to the bidders plans more detailed than had been our

FIG. 17.

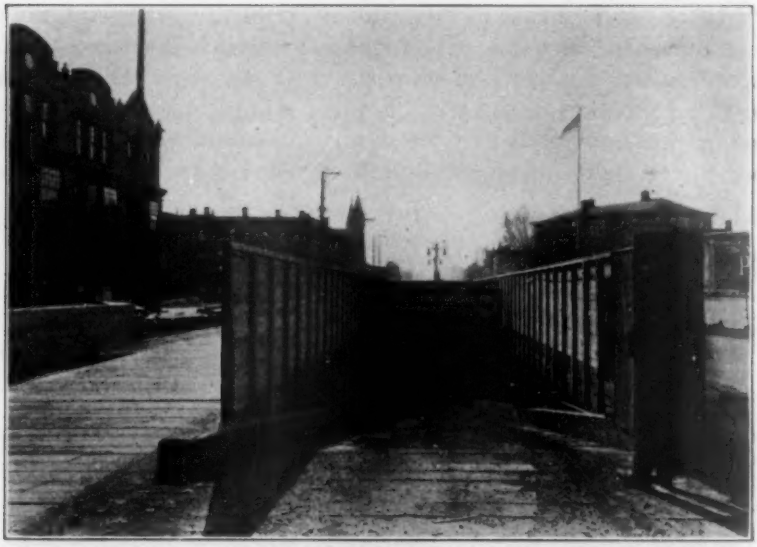


Span method of bracing and decking support—McGovern.

earlier practice were well worth while, and have had reflection in the unit prices bid and in the speed with which the work was carried on.

Our purpose was to keep the roadway of Broad Street open for traffic to the maximum extent consistent with the necessities of construction methods available and their bearing upon the cost and speed of the work. The duration of an interference was considered, as well as its nature and extent. On the first and second sections, complete decking was required. Traffic counts made during the process of decking and from time to time indicated that reasonable restriction of the surface kept open for

FIG. 18.



Typical ramp—McGovern.

FIG. 19.

Placing decking—Keystone.

traffic could be had without serious effect upon the public convenience. A natural diversion of traffic to adjoining streets and other routes was experienced, and the barring of heavy traffic from the temporary street surface by ordinance further served to reduce the volume of traffic to be accommodated. As a result of this experience, and in order to keep down costs and enable quicker work, the specifications for the third section, extending

FIG. 20.

Placing decking—McGovern.

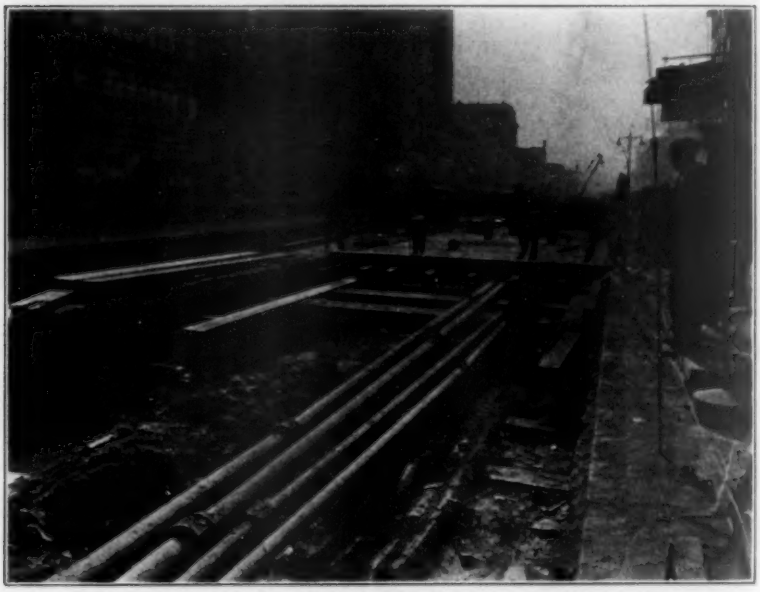
into the business district, reserved for traffic purposes a 25-foot strip on each side of Broad Street, leaving to the contractor for his use and purposes a strip 19 feet wide in the centre of the street. On the fourth section at the extreme north end some special street conditions exist which made possible a still smaller reservation of street surface for vehicular uses, and in some portions enabled work to be done in open cut.

On the section south of City Hall, the extremely heavy traffic conditions, both street and sidewalk, particularly between City Hall and Spruce Street, have been recognized in the portion of the specifications dealing with the methods of construction and

restoration. The purpose has been to minimize, as far as it is practicable to do so, the inconvenience and obstruction to property and business that to a certain extent is an inevitable result of work of this character and magnitude.

The decking is to be laid in three longitudinal strips and in a sequence and subject to restrictions that are intended to localize and minimize the interference with traffic. Construction opera-

FIG. 21.



Placing decking south of City Hall—Heyman-Goodman.

tions are to be confined to a fenced-in area in the centre of Broad Street, between intersecting streets, leaving a 24-foot driveway adjacent to each curb available for the free use of traffic. Underpinning operations in Broad Street north of Spruce are to be carried on from beneath the decking and, in general, sidewalks will be decked and maintained in service for their full width. Similar requirements have been fixed for the placing of the backfill, the removal of the decking, and the placing of the temporary paving.

The temporary and permanent relocation of gas mains in order to keep gas out of the trench was provided for under

separate contracts. Extensive relocation of large water mains in order to safeguard service as well as construction operations, and reconstruction of four large sewers crossing Broad Street, as well as the support, maintenance and protection of public utility structures and of buildings, etc., along the line of the work, were included in the general contracts, as were the temporary paving

FIG. 22.

Bracing and excavation in rock cut—McGovern.

of granite blocks on a gravel base and the restoration of sidewalks and other structures.

The following figures and Fig. 14 will give an indication of the magnitude of the work between City Hall and the terminal yard:

Subway excavation	3,131,000 cu. yds.
Concrete	373,000 cu. yds.
Structural steel	47,400 tons

Methods of Construction.—Much interest was aroused by the difference in the methods employed by the two contracting firms which carried on the work. The Keystone State Construc-

tion Company elected to proceed by decking the entire width of the cut, using the cross-bracing and posting method of timbering (Fig. 15) and carrying on the excavation work by hand tools under cover, spoil being carried by an industrial railway to fifteen shafts (Fig. 16) located about 600 feet apart, there hoisted to the surface and loaded from bins into trucks for disposal. On its later contract, similar methods were used, but with shafts

FIG. 23.

Bracing in rock cut—McGovern.

placed closer together. The shaft structures span one-half the width of the roadway.

Patrick McGovern, Inc., elected to first open and cover one-half of the street, supporting the decking on large "I" beams spanning the trench, and bracing the sides of the excavation from the "I" beams (Fig. 17), thus keeping the trench practically clear of obstructing timbering. Nine ramps (Fig. 18) were constructed about 900 feet apart, in the centre of the roadway, which enabled trucks to be driven from the street surface into the excavation, there loaded directly by air-operated shovels, and thence out again for disposal of the spoil. After the east

FIG. 24.

Erecting steel where span bracing was used—McGovern.

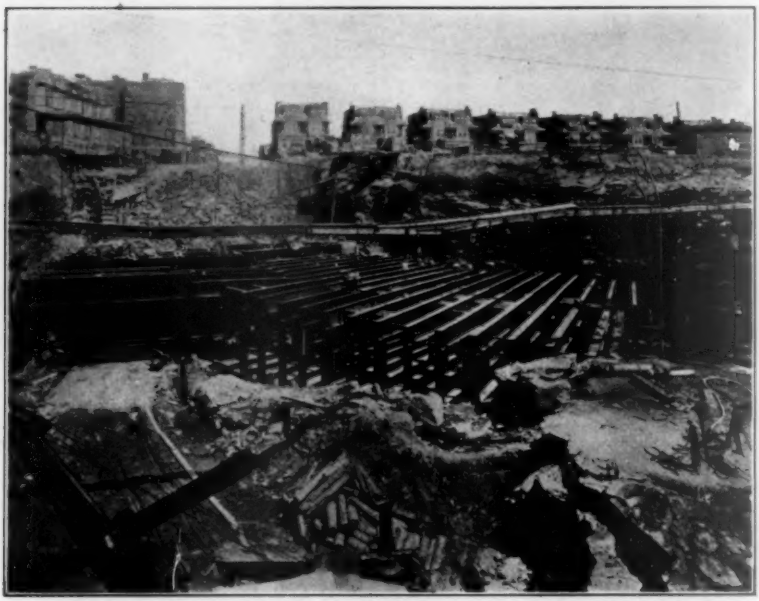
FIG. 25.

Erecting steel where posts and cross-bracing were used—Keystone.

half of the section was well advanced, work was begun on the west side.

The two methods of placing the decking and its support are shown in Figs. 19 and 20, and Fig. 21 shows a variant of the McGovern method being used by the Heyman-Goodman Company on the work south of City Hall. Figs. 22 and 23 show excavation methods and bracing in a deep rock cut on the

FIG. 26.



Open cut method at Broad Street and Grange Avenue—McGovern.

McGovern contract and Fig. 24 the erection of the steel beneath the temporary span bracing. Fig. 25 illustrates the condition under which steel is erected where the timbering and cross-bracing method of construction is employed. Fig. 26 shows some open cut work at Grange Avenue. Fig. 27 shows a traveller with roof forms used in concreting roof arches. Fig. 28 shows special roof bays at Pike Street to permit crossing of underground utilities.

The most burdensome features of subway construction from the public viewpoint arise from the operation of backfilling and the temporary paving. In general, thorough puddling and jetting

of the fill, supplemented by tamping under structures, etc., were relied upon to compact the fill. The temporary paving consisted of new dressed granite block, destined for later use in the permanent paving, laid on a gravel base. The difficulties of maintaining a reasonably smooth street surface, without paving foundation and on a green fill, under modern street loads, are obvious and necessitated considerable maintenance work. In

FIG. 27.

Traveller and roof forms used for concreting roof arches—McGovern.

spite of a very high grade of "temporary" paving and maintenance efforts, much criticism of the surface was encountered, with demands for early repaving.

Settlement of the fill is inevitable, and permanent paving placed too soon would before long present an unsatisfactory street surface, with added maintenance requirements and earlier need of repaving, thereby creating further interferences with traffic and involving a wasteful use of public money. For these reasons, the permanent paving was not put down until the fill had had about a year to settle, the decision as to any section

depending upon the age, depth and character of the backfill, and the settlement readings made by us from month to month. The permanent paving consists of the dressed granite blocks, laid on an 8-inch concrete base, with a bituminous mastic filler, considered the best type of paving for heavy loads on main highways. It has been completed from Callowhill Street to Clarkson Avenue, a distance of 28,160 feet, leaving only the relatively short sections

FIG. 28.

Depressed roof bays at Pike Street.

at the northern and southern ends to be done next spring, by which time the deep fills in these sections are expected to be in proper condition. These permanent paving contracts totalled some $886,000.

THE FERN ROCK YARD AND SHOPS.

Adequate yard and shop facilities, conveniently located with reference to the line and with ample connections between yard and line, are essential features of the system, and determinations with respect to them have recognized the requirements of the future and their expected development.

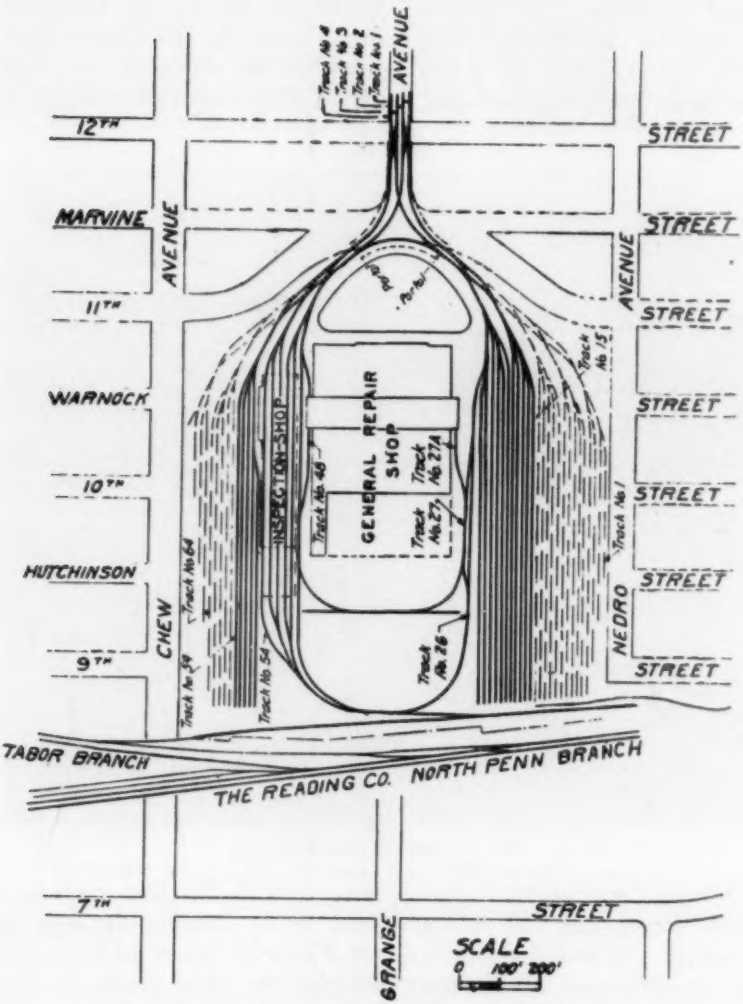
The Yard and Shop Site.—The site selected for shops, car storage, etc., is bounded by Chew Street, Nedro Avenue, Marvine Street and the Reading right-of-way, and embraces an area of about 32 acres. Its nearness to Broad Street, the favorable topography, and the adjoining railroad made the site almost ideal. With the exception of a few houses on the northern front the tract was totally undeveloped, with no streets opened through it,

FIG. 29.

Deep fill—east end of terminal yard.

although the confirmed street plan provided for five north-and-south streets and one east-and-west street running through the property. It was decided to divert Eleventh Street so as to skirt the western part of the tract, arrange the yard grades so that Ninth Street could be opened beneath the tracks as and when such opening becomes necessary, and to remove the others from the street plan. Fig. 29 shows the depth of the fill required towards the eastern end of the yard, which was made with spoil from subway excavations in Broad Street.

FIG. 30.



Terminal yard—general plan of track and buildings.

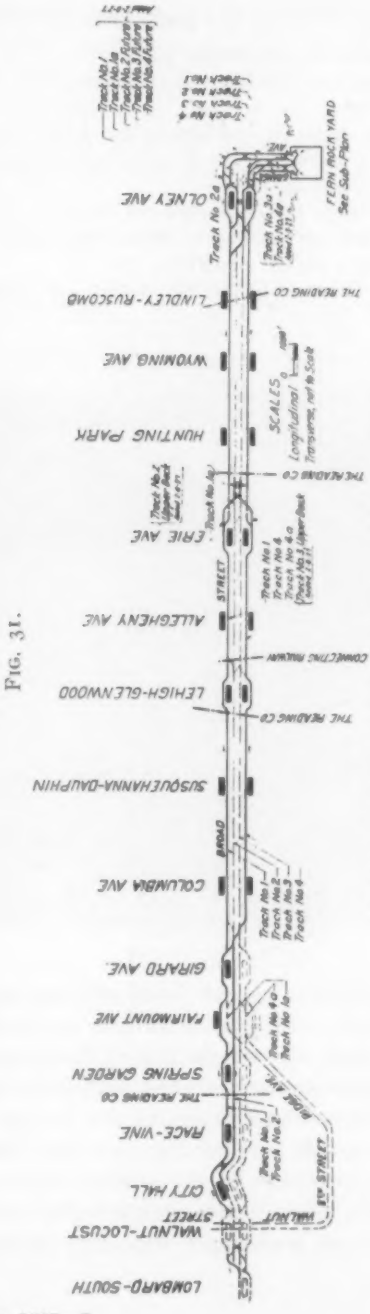


FIG. 31.—Initial and ultimate track plan—subway and yard connection.

The facilities provided in the yard area include:

(1) The two Grange Avenue subway portals.

(2) Inspection shop for the periodic inspection of all cars in service operating from this yard.

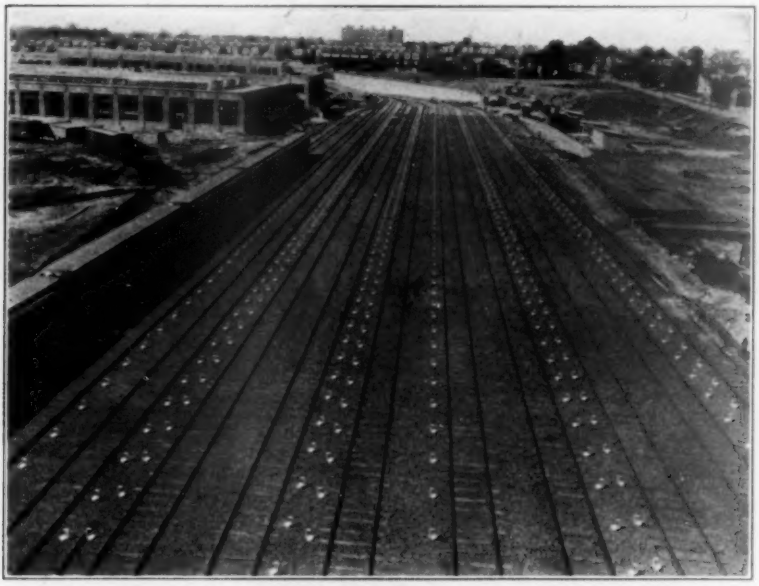
(3) General repair shops for overhauling and repair of subway equipment and of all cars that may operate on the Broad Street subway, its future extensions, tributaries and connecting lines.

(4) Open track storage for cars when not in use.

(5) Storage buildings and yard space for materials used in maintenance of permanent way, buildings, station equipment, etc.

(6) Steam railroad connection, for the receipt and shipment of freight.

FIG. 32.



North storage yard.

Convenient and direct access to all storage tracks and to the inspection and repair shops is a prime requisite for effective terminal facilities, and was sought for in the planning. As in all similar developments, numerous yard and building layouts were considered. The plan selected divides the storage yard into two parts; one on the north side of the plot and one on the south side, each equally accessible to the subway through the portals. By this arrangement ample space was left between the two parts for the shop buildings and other necessary storage area. The

general plan of tracks and buildings is shown in Fig. 30, and Fig. 31 shows the initial and ultimate track arrangement in the subway and in the yard connection under Grange Avenue. All car storage tracks are stub end, and service tracks are provided to connect the two yard sections, to provide access to the shop building, serve the material storage area and connect with the Reading Company tracks for freight delivery. Entrance for automobiles, trucks and other vehicles is made over a driveway

FIG. 33.

North portal at terminal yard.

entering from Eleventh and Grange and encircling the repair shop, thereby avoiding crossing any tracks except the spurs entering the repair shop. The yard areas will be lighted by floodlights on towers at the four corners of the yard.

The ultimate development of the yard area, which has been kept free of all poles and overhead wires, will permit the storage of about 450 cars, provide inspection shop facilities for these cars, and general repair shop facilities for 600 cars and upward, depending on improvements in shopping methods and future extensions to the shop buildings. The initial track installation will provide storage track for about 165 cars. A view of the

north storage yard is shown in Fig. 32 and the portal arrangement in Figs. 33 and 34.

The Shop Buildings.—Two main buildings have been provided, the inspection shop for frequent periodic inspections and minor repairs, and the repair shop for general overhauling, requiring more or less dismantling of the mechanical and electrical equipment and painting of the cars. This general arrange-

FIG. 34.

North portal at terminal yard.

ment is shown in Fig. 35, and exterior views in Figs. 36, 37 and 38. The yard and shops are in a purely residential district and we endeavored by architectural treatment and finish to meet this situation. A suitable entrance building (Fig. 39) and steel and concrete fence around the yard will be in harmony with this aim.

The usual frequency of inspection means that a substantial part, say from 8 to 12 per cent. of the total number of cars, will pass through the inspection shop each twenty-four hours. Maximum service from the equipment demands the largest possible number of cars be made available for "rush hour" periods and as inspections can usually be made in several hours, and if given

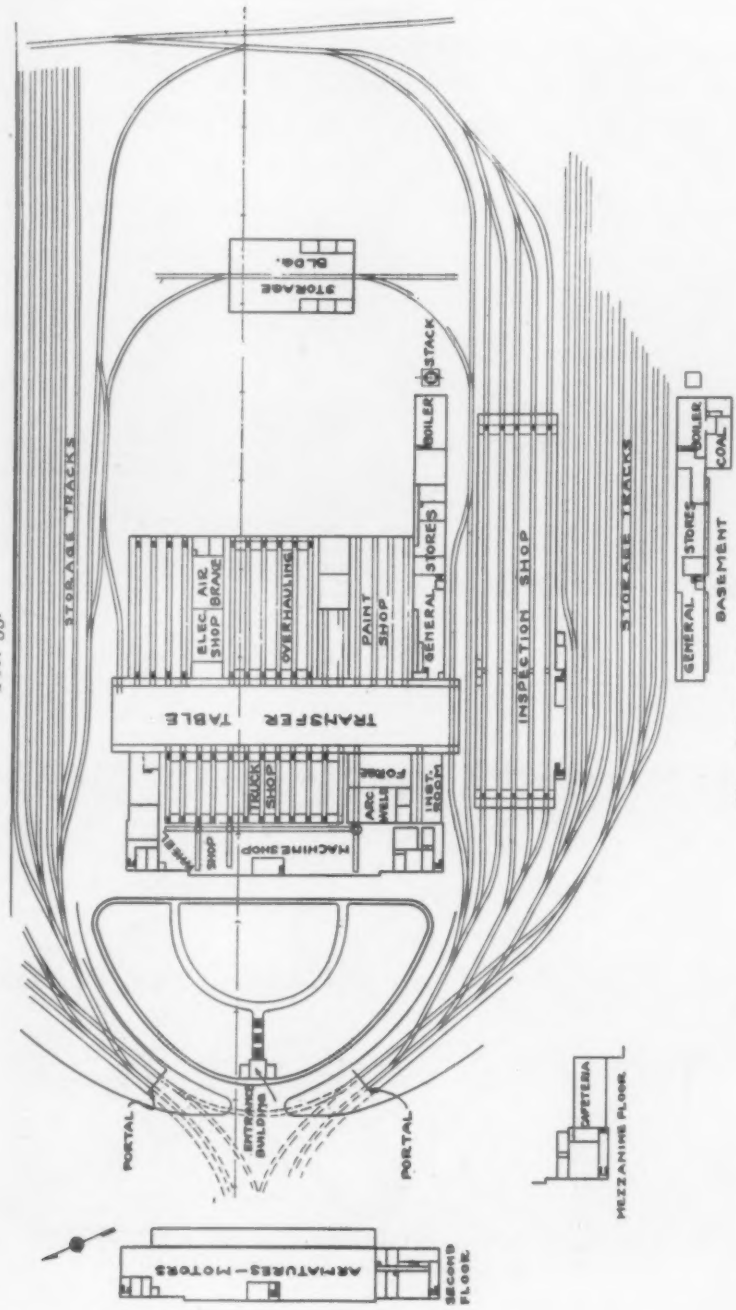


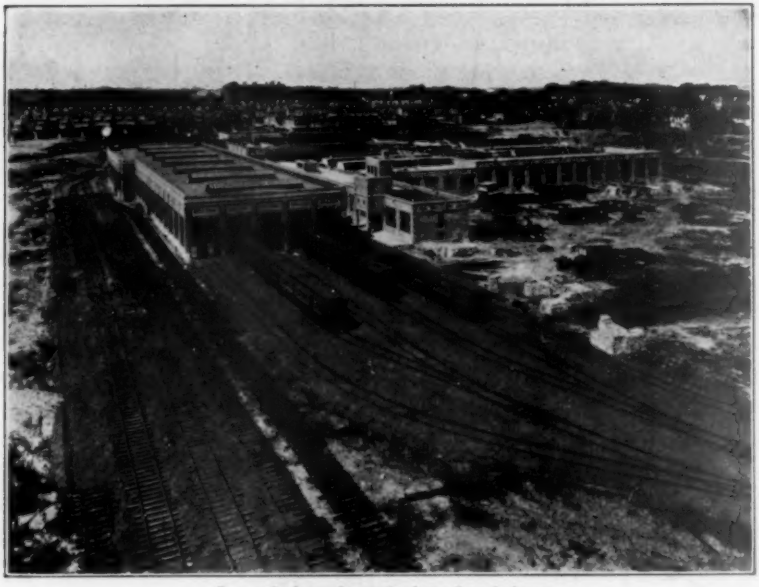
FIG. 35.

Plan of shops and storage tracks.

FIG. 36.

Repair and inspection shops and floodlight tower.

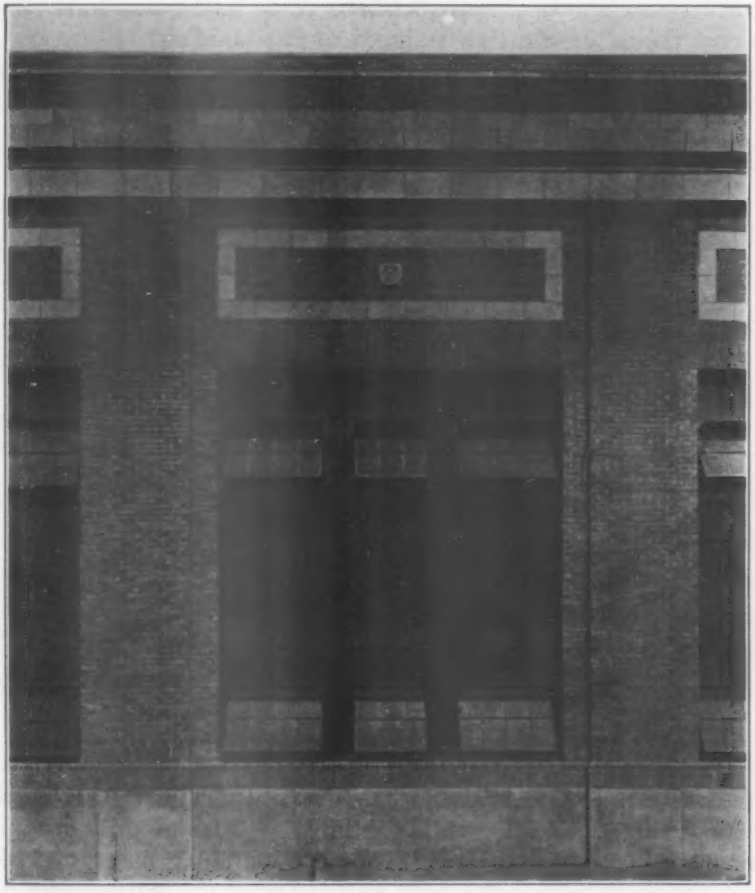
FIG. 37.



General view of terminal yard and shops.

proper facilities, can be made between such morning and evening rush periods either through the middle of the day or during the night. To this end the inspection shop has been made long enough to accommodate a full train and each track connected for

FIG. 38.



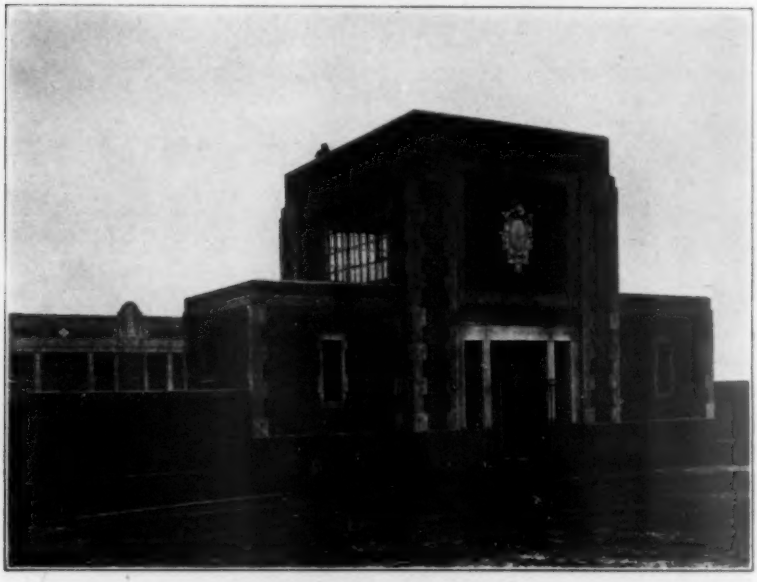
Architectural detail—inspection shop.

entrance or exit at either end. It is not expected that during the first few years of operation train lengths will exceed six cars and the inspection shop has been built to accommodate trains of this length, with provision made for future extension to accom-

modate eight-car trains. Inspection tracks are spaced 18 feet between centre lines to provide ample working space between cars, and all tracks are built over pits, with the floor between tracks depressed one foot below head of rail. The few pieces of machinery required in this shop will be housed in a two-story addition along the south side, which will also provide for oil room, storage room, work benches, office space, and toilet and locker rooms for the men assigned to this building.

The plan of the general repair shop embodies the use of a

FIG. 39.



Entrance building—terminal yard.

car transfer table to move cars into and out of the shop and to move cars and trucks to the various departments during the course of repairing, overhauling, and painting. The building is approximately 360′ × 380′, with an " L " extension along the south side 36′ × 160′. The transfer table travels across the entire width of the building, and sufficiently beyond each side for the connections to the yard tracks. The jacking shop, overhaul shop, car washing and paint shop, and spaces for miscellaneous repair work, are to the east of the transfer table, and the truck, forge and welding shops, etc., on the west side, and beyond these are the wheel, axle,

and machine shops with motor and armature departments on the second floor. A high overhead crane operating over a well will enable motors, etc., to be hoisted from the truck shop to the second floor, which is also served by a freight elevator. Twenty-ton cranes are provided in the jacking shop for lifting car bodies, and fifteen-ton cranes serve the truck shop tracks, with smaller cranes serving the machine shop floor and the electrical shop on the second floor.

Ample storeroom facilities on the main floor and in the base-

FIG. 40.

Administration building at Broad Street and Grange Avenue.

ment, together with the heating plant, are located in the extension of the main building, and provision has also been made for offices, locker and toilet rooms, first aid, etc., at convenient locations.

The portion of the shop to the west of the transfer table is both the present and final development, due in part to the building arrangement selected and in part to the fact that the greater portion of the heavier machinery required for the maintenance of the initial equipment of cars will be sufficient to care for a very much larger number. Additional capacity in the jacking shop, over-

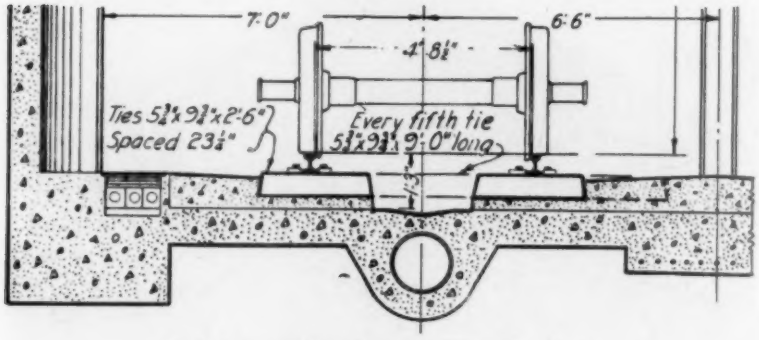
haul shop, paint shop, etc., can be provided when needed by extending the main building to the east.

An administration building, to house the operating offices and provide for trainmen's waiting room, etc., is located on the southeast corner of Broad Street and Grange Avenue. The exterior of this building is shown in Fig. 40.

THE TRACK STRUCTURE.

For initial operation two tracks, of standard gauge, are being installed between City Hall and Olney Avenue, with a double crossover located just north of City Hall in order to permit the

FIG. 41.



Typical cross-section of tangent track and roadbed.

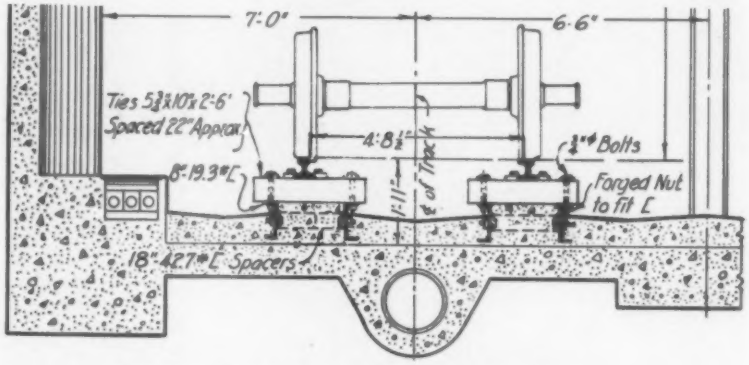
use of the City Hall Station as a stub-end terminal during this period, and with several crossovers just south of Olney Avenue for similar purposes. Provision has been made in the subway structure for emergency crossovers just north of Girard Avenue, Glenwood Avenue, and Erie Avenue. In order to provide the maximum flexibility of train movements and to avoid interference with operations later on, the complete system of tracks and special work has been installed through the Olney Avenue Station and through the yard connection to the portals.

Types.—In selecting the type of track structure for the subway, the major characteristics sought for were: Safety of operation; permanence of alignment and surface, and long life of the structure, in order to keep to a minimum the frequency of and average cost of maintenance and renewals; a construction that would facilitate keeping the subway floor in a clean and sanitary

condition; and with due consideration of the costs of construction and operation. It was determined that a solid concrete track type, rather than the more usual ballasted type, best met the requirements.

The type selected for tangent track, and this covers the major portion of the subway trackage, consists of ties partially embedded in concrete, as shown in cross-section in Fig. 41. This type was not considered advantageous for use under "special work," such as switches, frogs, crossings, and short radius curves. The greater wear and strains imposed on the track at such locations, with resulting necessity for comparatively frequent adjustment

FIG. 42.



Typical cross-section of track and roadbed—channel type.

and renewals of portions of the structure, make it desirable to obtain a more positive anchorage of the track to its foundations and to so arrange the track elements that they may be adjusted or replaced at lesser cost and with less interference with the operation of the trains. In the type selected for this purpose, the ties are bolted to channels, which in turn are embedded in a concrete track floor, as shown in Fig. 42. The type selected for tangent track has a material advantage for that purpose because its lesser depth from top of rail to the bottom of the track structure reduces the required depth of the subway tube, with a resulting substantial reduction in construction costs.

Ties.—Long leaf southern yellow pine was selected for use as ties and a grade specified that would insure the best obtainable within reasonable limitations of cost. The rough sawn timber

was required to be air-seasoned for a period of not less than five months before being cut to length and dressed to prescribed dimensions. After cutting and dressing, holes were bored for screw spikes and tie bolts and the finished ties creosoted with five pounds of oil per cubic foot by the empty cell process. The creosoting was an added precaution to protect from decay the small amount of sap wood permitted by the specifications. The ties as secured contained over 90 per cent. heart wood.

The ties are cut from 6″ × 10″ timber and surfaced to a

FIG. 43.

Method of bracing tangent track for concreting.

uniform thickness of 5¾ inches. In the straight track type of construction, the ends of the ties are bevelled to form an anchorage to the floor. Short ties (30 inches long) are used under each rail and spaced 23¼ inches between centres with every fifth tie 9 feet long to engage both running rails and to provide support for the conductor rail. In the channel type short ties are used throughout except where switches, frogs, crossings, etc., require the use of various greater lengths.

Rail and Fittings.—The rails used in the subway are one-

hundred pound A.S.C.E. section, sixty-two feet in length. This particular section was selected largely on account of its wide base as compared with the weight of the rail. This wide base, in conjunction with ties having a 10-inch face, gives sufficient tie bearing to justify the omission of tie plates.

Screw spikes with cast-iron clips to engage the base of the rail are used throughout the subway and splice bars of a type

FIG. 44.

Method of concreting tangent track.

recently developed and embodying the so-called "head-free" feature are used.

Special Work.—The special track work, involving switches, frogs, crossings and curved rail, is of extremely rugged construction, following generally well-established practice for such work where subjected to heavy traffic. Cast manganese steel is used at practically all points of maximum wear and most of the switches in the subway are of a specially designed type which has given excellent service in the Market Street subway.

All curves of short radius are protected with guard rails, and guard rails have also been installed at all other locations where a

tendency toward derailment might exist. The running rail in all special work is one-hundred pound A.S.C.E. rail, the same as the running rail in the straight track.

Yard Track.—The nature of yard operations and the fact that the yard track is in the open reduced the importance of some of the characteristics sought for in the concrete type of construction used in the subway, and led to the adoption of the ordinary

FIG. 45.

Completed tangent track.

ballast type of construction for the yard track. The special track work at the western end of the yard, which is the part subjected to the greatest traffic, is ballasted with crushed stone. The remainder of the yard, including the straight track and the special work at the eastern end, being ballasted with cinders.

Six-by-eight ties are used in the yard instead of the six-by-ten as used in the subway. They are of sawed yellow pine but of lower quality than used in the subway. On account of this lower grade and because they are exposed to all conditions of weather, they have been treated with ten pounds of creosote oil per cubic foot, applied by the full-cell process. Rail and fittings in the

yard are generally the same as in the subway, except that the rail is in standard lengths of 33 feet and screw spikes are used only at special work, cut spikes being used on the straight track. The special work in the yard is substantially the same as that in the subway except that the majority of switches, on account of the lesser number of car movements over them, are not manganese steel but of a cheaper type, considered more appropriate for the expected use and conditions.

Construction of Subway Track—General.—It is obvious that the types of track selected for the subway call for extreme care and accuracy and for the highest grade of workmanship and materials in construction, particularly as to alignment and surfacing and concreting. Once concreted, there is practically no possibility of adjusting line or surface. To meet this situation and to indicate the care and accuracy that would be demanded in the work, the track laying plans and specifications not only showed the desired results but also presented as a guide and standard a complete scheme of assembling, lining and surfacing the track and of holding it in position during concreting. The plan specified, with some minor variations, was used by the contractor and produced the desired results.

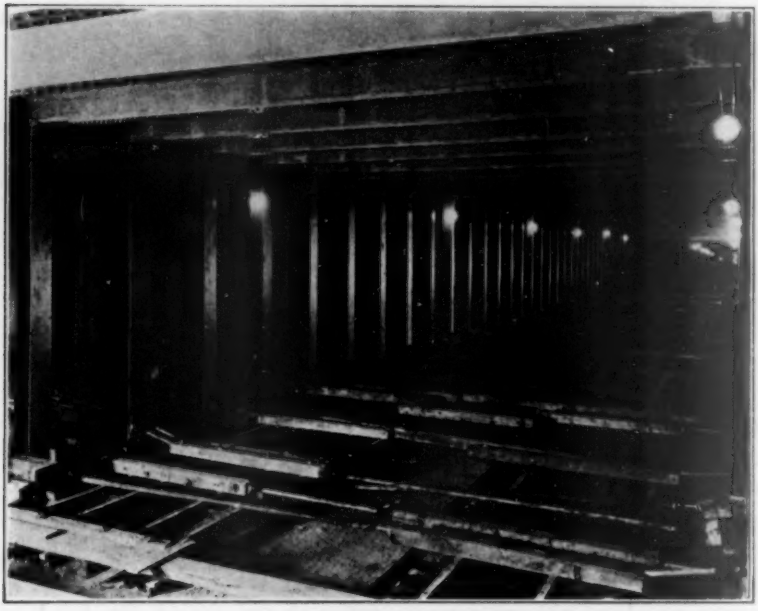
With the exception of the aggregate for the concrete, all track materials were taken into the subway through the portals and distributed by motor trucks. The aggregate was taken into the subway through certain temporary roof openings or through ventilation wells, and then trucked to the points of use.

Construction of Tangent Track—Type.—In the straight track type the ties were placed on the subway floor approximately in proper position; the rails were then laid on top of the ties and splice bars and bolts installed, leaving the proper joint openings as prescribed for the prevailing temperature. The exact location of each tie was marked on the rail, after which the cast-iron clips were placed and the spikes driven by pneumatic spike-driving machines. A portable gasoline-driven compressor furnished the air power.

The next operation included surfacing, lining and bracing the track preparatory to concreting. For this purpose twelve screw jacks were placed in pairs—one on each side of the track, at intervals of about fifteen feet. Steel bars placed under the rails, each resting on a pair of jacks, provided the means of raising

the track to proper surface, lengths of 60 to 75 feet being raised at one operation. After raising to proper grade the track was carefully aligned while supported on the steel bars. To hold the track thus surfaced and lined securely in position for concreting, precast concrete blocks of a depth about equal to the thickness of the track concrete were placed under each rail at intervals of 11 feet (two column spaces) and wooden wedges driven

FIG. 46.



Method of bracing channels for concreting.

between these blocks and the base of the rail. Screw trench braces similarly spaced were used to secure the track against lateral movement by bracing against the adjacent steel columns. These braces were placed at a considerable angle from the horizontal and in this position resisted any tendency to "float" the track during concreting. Survey lines had of course been previously established by carefully marking points for line and grade at close intervals. After the track had been braced as above, the screw jacks were removed, and forms placed for the concrete. This operation is shown in Fig. 43.

The concrete mixer was operated in the track space adjacent to the track under construction, the mixer having a specially designed chute to permit manipulation between columns as the mixer was moved along to keep abreast of the work. The concrete was a 1-2-4 mix of sand and gravel with coarse aggregate limited to one inch maximum and mixed comparatively wet to insure complete filling under the ties. Special care was exercised

FIG. 47.

Concreting of channels completed.

to secure this result. (Fig. 44.) After the concrete had received its initial set, all braces, wedges and forms were removed and the concrete surface finished. At the beginning the work progressed rather slowly, due to the need of "ironing out" various difficulties that were encountered, but as it got well under way it was possible to complete as much as 900 feet of track per day of nine hours with one concrete mixer, and to make equal speed in the preceding operations of spiking, lining and surfacing. Fig. 45 shows a stretch of completed track.

Constructing Channel Type.—In the channel type of construction a different method of track assembly was necessary. The

channels were assembled on the subway floor as near as possible to their proper location, with joint splices and separators properly bolted. Six-by-six-inch temporary ties of varying lengths were laid across the top of the assembled channels and secured to them by means of hook bolts engaging the top flanges, the holes in the ties being so located as to hold the channels in their proper relation to each other, the ties also serving to maintain the tops

FIG. 48.

Completed special work in place on channels.

of all channels in the same plane, a very essential requirement. (Fig. 46.)

The channels thus assembled were carefully surfaced and lined in much the same manner as the straight work and similarly supported and braced, except that the use of the precast concrete blocks was not necessary, the support being secured by driving wooden wedges between the floor and the bottom of channels. Where curved track was involved, necessitating superelevation of the outer rail, such superelevation was provided in the channels so that a uniform depth of ties could be used throughout. The concrete was then placed to the finished floor grade, except the

portion between channels which forms the support for the ties. This was left 3 to 4 inches below grade until that surrounding the channels had taken its initial set, at which time the bracing and temporary ties were removed and then the remaining concrete was placed and carefully screeded to a surface exactly conforming with the top of channels. It may be well to say here that in this type of construction the channels are not for the support of the

FIG. 49.

Completed yard track, roadbed, and third rail.

track, their principal function being to provide anchorage to keep the track from a vertical or lateral movement on its foundation, the concrete between channels forming the necessary support. (Fig. 47.)

After the concrete had properly set, the exposed leg of the channels was painted and the ties distributed in their proper location and securely bolted to the channels, the bolts being placed head up with a special nut conforming with the channel flange. By this means any tie can be subsequently removed and replaced without removing the rail. The rails, switches, frogs, etc., were then placed on the ties, carefully lined and screw spiked. While,

in the straight track type construction all holes were prebored, in the channel type only the standard length short ties were prebored for tie bolts, all other holes, including those for screw spikes, being bored in place. Fig. 48 shows some completed special work.

While the yard track construction did not involve any special methods, Fig. 49 shows its general features and appearance.

POWER SUPPLY, CONVERSION, AND DISTRIBUTION.

General Determinations.—The electrical features of the Broad Street subway include a wide range of equipment, beginning with the supply lines from existing power sources, and covering the conversion, distribution, and use of the power.

In the selection of substation sizes and locations, the ultimate power taken by the trains was used as the basis of the determinations, since the power used by the trains constitutes by far the greatest portion of the total requirement. The ultimate rush-hour operation was assumed to consist of eight-car trains running on two-minute headway on all four tracks, with northbound trains carrying an average load of 150 passengers per car (72,000 per hour) and southbound trains loaded to an average of thirty-five passengers per car. Since northbound trains will be running against the average grade, the evening rush hours are the hardest and these conditions were, therefore, used in determining the maximum substation loads.

With the schedule outlined above, and assuming a loaded car weighing 66 tons accelerating at an average rate of 1.6 m.p.h. p.s. and braking at 2.0 m.p.h. p.s., train curves were drawn for an average run, using characteristic curves of standard motors of various sizes. The results of these calculations fixed the motor requirements at approximately 400 h.p. per car, and because of the obvious advantages of large motors it was decided to use two 210-h.p. motors on each car. While it would have been possible to equip one half the cars with four motors each and make the other half trailers, the operating advantages of having all cars motorized and the disadvantages of the necessarily heavier and more cumbersome control equipment required by four motors, were considered as sufficient to warrant the greater cost of the scheme selected.

Having determined the proper motor size, continuous train

curves for northbound and southbound local and express trains were then drawn, assuming an average potential of 575 volts on the contact rail, and studies of various numbers and locations of substations were made from the power requirements as shown by these curves.

Substation Spacing and Loads.—Past experience with a four-track subway rapid transit line, similar to Broad Street subway, has indicated that the feeder capacities and voltage drops during peak loads are within satisfactory limits when substations are spaced about two miles apart, and the results of the power requirement studies for the Broad Street subway bore out this experience. Considering the first section of the Broad Street subway, with a branch on Ridge Avenue, it appears logical to locate a substation near this junction point, and therefore the Mt. Vernon Street site was chosen. This substation will carry the load of two-track initial operation to City Hall (a distance of approximately 4400 feet along Broad Street), and by the time traffic requires four-track operation through City Hall the subway will be extended to the Lombard-South Station and another substation will be located in the vicinity of South Street.

The next substation to the north is located on Cumberland Street, approximately 10,000 feet along Broad Street from Mt. Vernon Street, or approximately 10,600 feet between substations. The farthest north substation is on Louden Street, which is approximately 13,000 feet from Cumberland along Broad Street, or approximately 13,600 feet between substations. This station will feed the north section of the subway proper, and will also supply the Fern Rock Yard with D.C. power.

The method used in calculating the loads on the substations made it possible not only to determine the load on each substation during the maximum hour, but also to compute the peak loads on each track during any five-second period, either assuming all trains exactly on schedule or assuming any trains five, ten, fifteen or any number of seconds (in multiples of five) behind schedule. Various "off schedule" combinations were tried, but it was finally decided to assume all trains exactly on schedule, but to assume that the peaks occurred simultaneously on all tracks; the improbability of the occurrence of the later condition giving sufficient margin over the calculated load to care for the possible actual five-second peak load.

The substation loads, as calculated by the above method, are as follows:

	Max. Hr. K.W.	Peak K.W.
Mt. Vernon	9700	21,600
Cumberland	9200	21,700
Louden	9200	20,500

Since the peak loads are something more than twice the maximum hour loads, and since the two-hour rating of synchronous converters is generally 150 per cent. of the continuous rating, it is evident that the requirements called for converters having at least a five-second rating of 300 per cent. of their continuous capacity. The converters installed have a continuous rating of 3000 k.w., with 150 per cent. for two hours, and 300 per cent. for three minutes, the large capacity of the individual machines having been selected because of the greater power and space efficiency of the large sizes, being particularly important in these installations, owing to the value of the land upon which it was necessary to locate these substations and the cost of suitable buildings.

The number of converters to be installed in each substation for the ultimate capacity of the subway will be four. This number includes one spare in each station. For the initial two-track operation two converters are installed in each substation, and these will easily take care of the estimated loads for the year 1930, in which the schedule has been assumed as six-car trains operating on a two-minute headway.

Power Supply.—Power for the operation of the Broad Street subway will be purchased from the Philadelphia Electric Company at 13,200 volts, three-phase, 60 cycles. In order to minimize the possibility of a complete shut-down of the subway due to loss of power, each substation will be supplied direct from a different generating station and, since any two substations will be sufficient to enable trains to continue in operation at reduced speed, the chances of a complete shut-down from this cause are very remote.

Substation No. 4, on Louden Street, will be fed from the Richmond generating station; Substation No. 5, on Cumberland Street, will be fed from the Hunting Park substation of the Philadelphia Electric Company, ultimately to be supplied from

Conowingo; and Substation No. 6, on Mt. Vernon Street, will be fed from the Delaware generating station.

The power cables, both incoming and outgoing, are all in underground conduit, and the A.C. supply is, in all cases, carried over duplicate three-phase cables, either one of which is capable of carrying the normal two-track load.

Substations and Equipment.—The locations of the substations, in residential districts, made it imperative that features such

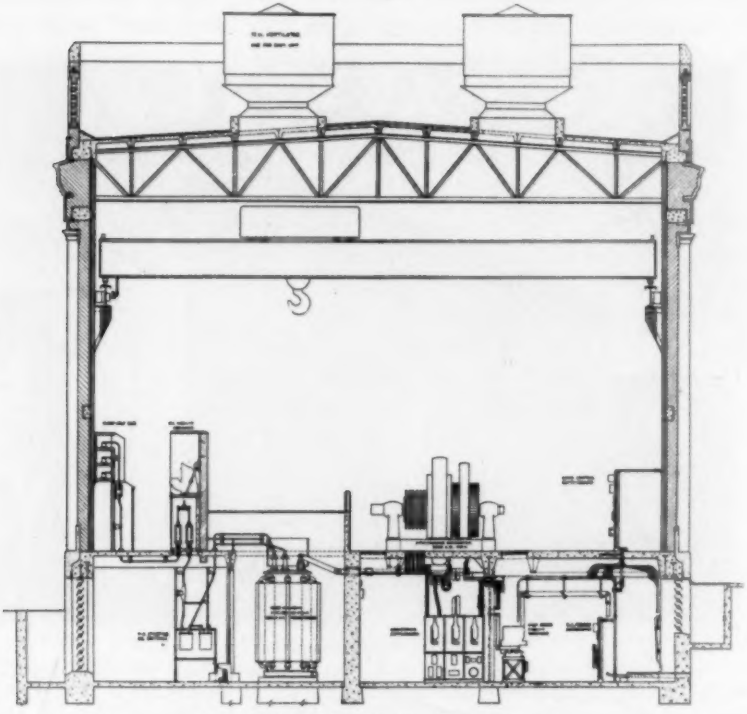
FIG. 50.

Louden Street substation.

as noise or objectionable architecture be reduced to a minimum, and for this reason the architecture of the buildings is such that they would be a credit to any section, residential or otherwise. The noise is minimized by making the buildings entirely closed, except for the ventilating louvers, which are placed below the street level and through which cool air is drawn. The heated air is expelled through ventilators in the roof, the entire ventilation being due entirely to natural circulation of air. Another feature which will reduce the possibility of noise is the presence of air space in the walls of the substations. An exterior view of the Louden substation is shown in Fig. 50.

In the arrangement of the equipment in the substations, every effort has been made to make the best possible layout from the standpoint of safety and ease of operation, all power circuits being located below the level of the main floor. A cross-section of the Louden station is shown in Fig. 51, a plan of the main floor in Fig. 52 and a wiring diagram in Fig. 53.

FIG. 51.



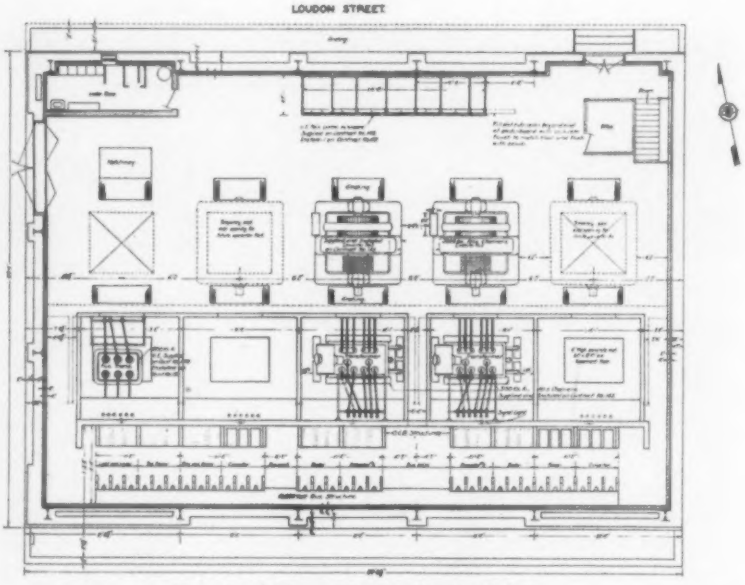
Cross-section of Louden Street substation.

Each incoming A.C. cable is carried direct to disconnect switches, then through an oil circuit breaker to another disconnect switch, and then to a 13,200-volt A.C. bus. Each transformer is fed from this bus through disconnect switches and a main oil circuit breaker and a Star-delta starting switch. Bus bars from the transformer secondaries lead directly to the A.C. end of the synchronous converters. The D.C. ends of the converters are connected through a circuit breaker to a common 630-

volt positive bus located in the basement directly below the converters. From this positive bus the contact rail feeder circuits are carried, through feeder panels, to the feeder cables which leave the building at the side opposite to the incoming cables.

The converters, of which two are installed in each substation for initial operation, are rated at 3000 k.w., continuous load,

FIG. 52.



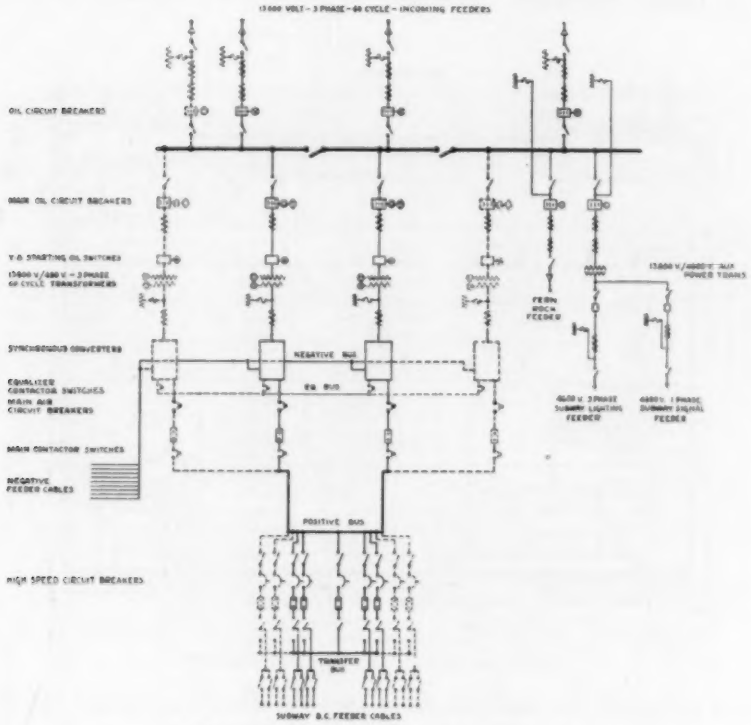
Plan of main floor of Louden Street substation.

and are good for 150 per cent. load for two hours and 300 per cent. load for three minutes. Two of these units are shown in Fig. 54. They are compound wound, 60-cycle machines and are the largest 60-cycle converters ever built. In addition to their size, they have another unusual feature in the armature windings. These windings are of the so-called "frog-leg" type, which consists of a combination of lap and wave windings, thus eliminating the necessity for cross-connections. The transformers supplying the converters are rated at 3150 k.v.a. at 13,800 volts and are three-phase, 60-cycle oil-cooled, the latter feature being a departure from the usual practice of using air-cooled transformers

in such installations. Fig. 55 shows one of these being lowered into place.

Another unusual feature is the remote control of all switches in the power circuits. The operators will not handle any switches carrying train power current, as these switches are all located in

FIG. 53.


13000 VOLT - 3 PHASE - 60 CYCLE - INCOMING FEEDERS
OIL CIRCUIT BREAKERS
MAIN OIL CIRCUIT BREAKERS
Y-Δ STARTING OIL SWITCHES
13000 V/600 V - 3 PHASE 60 CYCLE TRANSFORMERS
SYNCHRONOUS CONVERTERS
NEGATIVE BUS
EQUALIZER CONTACTOR SWITCHES
EQ. BUS
MAIN AIR CIRCUIT BREAKERS
MAIN CONTACTOR SWITCHES
NEGATIVE FEEDER CABLES
POSITIVE BUS
HIGH SPEED CIRCUIT BREAKERS
TRANSFER BUS
SUBWAY D.C. FEEDER CABLES
FERRY 600 V. FEEDER
13000 V/4600 V. AUX. POWER TRANS.
4600 V. 3 PHASE SUBWAY LIGHTING FEEDER
4600 V. 1 PHASE SUBWAY SIGNAL FEEDER

Wiring diagram—Louden Street substation.

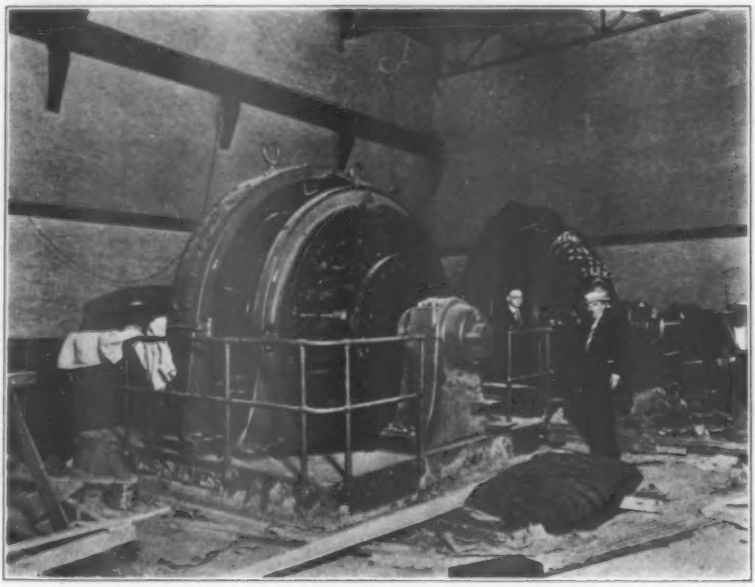
the basements and controlled from the switchboard on the main floor.

Distribution.—Power is to be carried from the substations to the subway in underground conduits. For initial two-track operation there will be eight 2,000,000-C.M. cables in the positive side and six 2,000,000-C.M. cables in the negative side of the circuit from each substation; while for the ultimate four-track operation the number of these cables will be doubled. Switching

rooms are provided in Broad Street at the streets on which the substations are located, and the positive cables from the substations are tied in with the contact rail through remote controlled circuit breakers located in these rooms, or in recesses in the subway retaining walls.

From the switching rooms two 2,000,000-C.M. cables are run to each contact rail section. The contact rail is of the over-

FIG. 54.



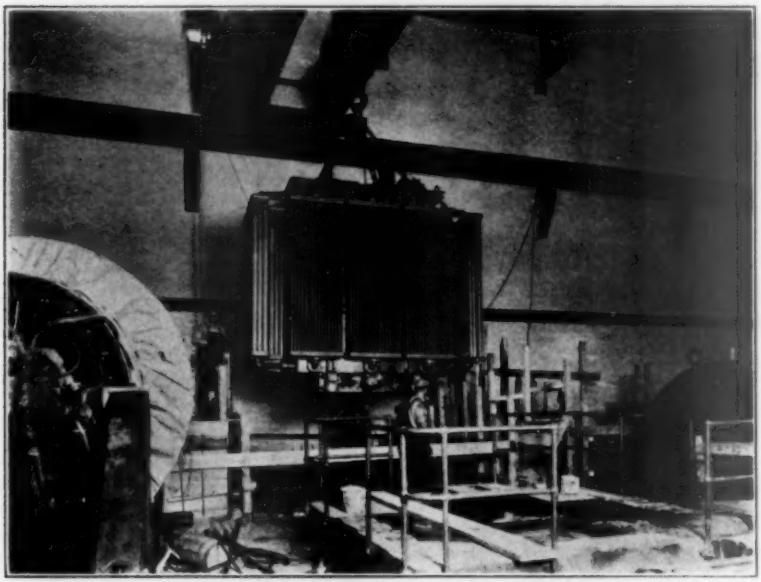
Rotary converters—Louden Street substation.

running type, 39 feet long, weighs 150 lb. per yard, and is made of soft steel having high conductivity. No feeders parallel to rails are used in either positive or negative circuits. Protection from the contact rails is obtained with a horizontal protecting board of the type generally used with the over-running rail. The rail is carried on porcelain insulators mounted on long ties located at 9-foot 9½-inch intervals, and is anchored in the usual manner in approximately 1000-foot sections, with expansion joints separating the sections. (Fig. 49.) The bonding of this rail is accomplished by bolting on two solid copper fish-plates at each

joint and by welding adjoining rail heads. The copper fish-plates are then soldered to the webs of the adjoining rails.

The negative or return circuit is entirely through the 62-foot, 100-pound running rails. Each joint is bonded with two 250,000-C.M. gas-welded bonds 13½ inches long. Due to the short lengths of the running and contact rail bonds and the high electrical efficiency of the welded and soldered connections to the

FIG. 55.



Oil-cooled transformer—Louden Street substation.

rails, the conductivity of the entire circuit approximates that of continuous rail, thereby reducing to a minimum the voltage drop with its consequent power loss, slower operation of trains, heating of motors and poor lighting in the cars. The tracks are cross-bonded at each passenger station, in addition to other cross-bonding through special work north of Olney Avenue. In normal operation all sectionalizing and equalizing switches are kept closed, thus tying the three substations solidly together through the contact rails. Sectionalizing joints are located at substation feed-ins, while equalizing points are located midway between feed-ins, at the portal, and at City Hall. The breakers located

at feed-in points are automatic opening, remote closing, 3000-ampere breakers. Thus they will open on an overload or short circuit, but cannot be closed except by a substation operator.

THE SIGNAL SYSTEM FOR THE BROAD STREET SUBWAY.

General.—The automatic block signalling and interlocking systems for the initial local track installation of the Broad Street subway are of the most modern type, both the apparatus and the installation being such as to give the highest degree of safety and reliability in high-speed subway service.

The salient features of the signal installation are as follows: Alternating-current power at 60 cycles used for signals and interlockings; double rail track circuits, except at interlockings and in yard; overlap signal control; automatic three-position, color-light signals; electro-pneumatic automatic train stops; semi-automatic electrically controlled block and interlocking signals; non-automatic electrically controlled dwarf and permissive signals; speed and time control signals; electro-pneumatic switch operating mechanism; impedance bonds and track connections; and interlocking machines and a yard switch control panel.

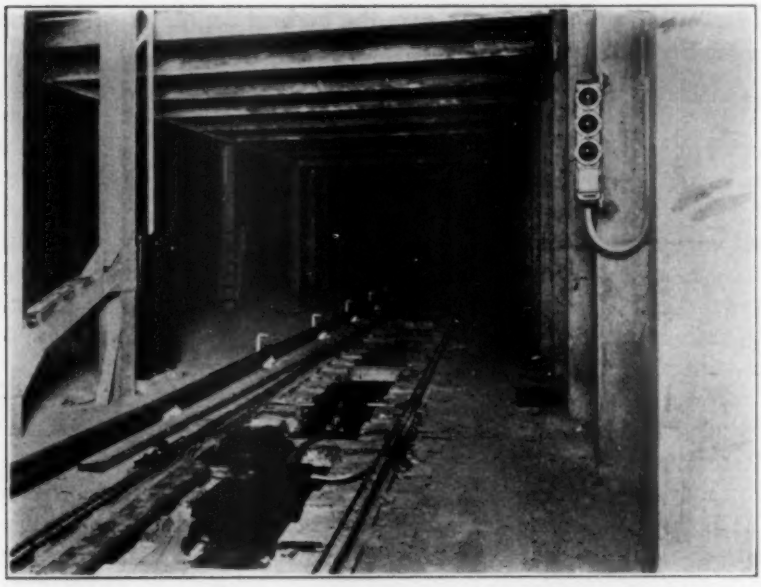
Power Supply.—Electrical energy for the operation of the signal system will be supplied from the Mt. Vernon and Louden Street substations. The supply from the Louden Street substation may be considered an emergency source of energy. Normally the energy will be taken from one set of feeders, but duplicate distribution cables are provided on either side of the subway structure and may be sectionalized at each substation. Automatic selector switches are provided at each 4600/110 volt distribution transformer location along the line so that in event of failure of a feeder or local transformer the signal load for the section will be automatically thrown over to the duplicate service, and automatically restored to the original source when that line is again energized. The signal power requirements for the ultimate four-track installation total about 65 k.v.a.

Signals.—With first consideration for the safety of passengers, studies were made of roadway, signal equipment and train-operating characteristics, so that signals might be located to provide maximum train capacity of tracks. These elements included profile and alignment of roadway, location of stations and interlocking plants, acceleration and braking rates, speed time

and time distance curves and the normal and maximum attainable speeds for each run for the equipment to be operated, as well as the visibility of the signals and the simplicity of the scheme of aspects displayed by them.

The signal locations or block spacings are laid out for eight-car trains operating on a two-minute headway, although the

FIG. 56.



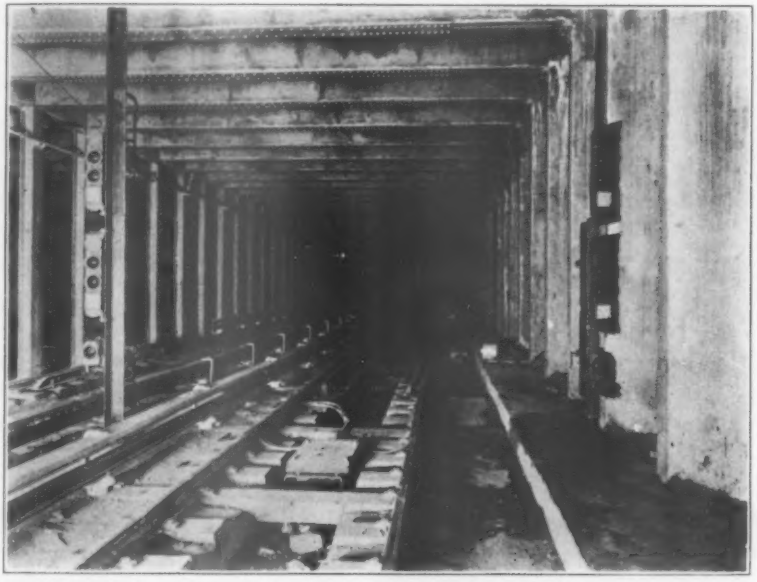
Typical single arm automatic subway signal and impedance track bond.

majority of spacings allow for somewhat less than one-and-a-half-minute headway, thus providing for a normal single-track capacity of approximately twenty-three eight-car trains on the line, operating at a round trip scheduled speed of 16½ m.p.h. In every case the length of a block is 150 per cent. of the emergency braking distance required by the train, at the maximum speed which can be obtained at that point.

The automatic signals (Fig. 56) are of the three-indication, color-light type, equipped with 5⅜-inch lenses of green, yellow and red, and 14-volt, 5-watt lamps in duplicate. Home signals at interlocking plants consist of two-three indication subway style, color-light type, with the same lens and lamp equipment,

and displaying two or three lights in a vertical row to indicate which route is set up, and whether or not the track ahead is occupied. In all cases the caution control of a signal is carried in the two blocks in advance, so as to obtain "overlap control" providing for two red signals protecting the rear of a train at all times. Fig. 57 shows a double arm, interlocking signal, with

FIG. 57.



Double arm interlocking signal and permissive signal.

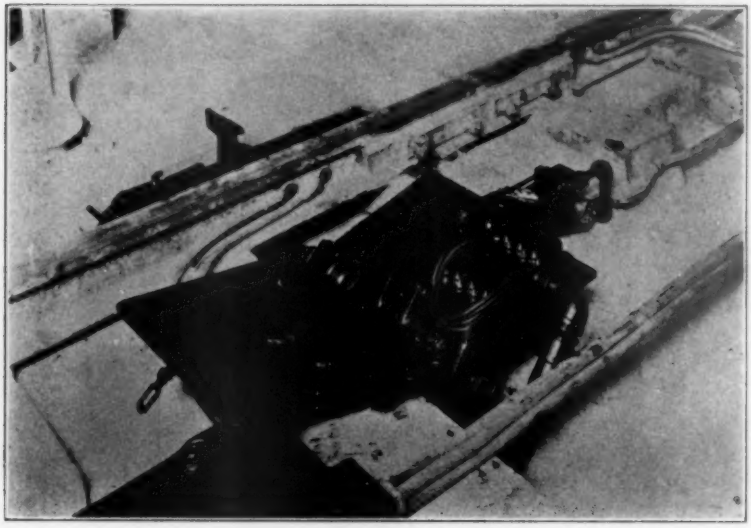
the yellow permissive signal, used in locations such as Grange Avenue where operation is in both directions.

Speed control signals have been placed on the southbound track south of Olney Avenue, where a long 3 per cent. down grade is encountered, on the southbound track leading off the upper deck at Erie Avenue to take care of a 3½ per cent. grade, and at several other locations where curves make automatic speed control desirable.

Automatic and semi-automatic train stops have been provided to operate in connection with every automatic block signal and with every interlocking home signal. The stops are of the trip type and are located on the left side of the track approximately

opposite the signal with which it operates. A trip arm extends 2½ inches above the top of the running rail when in the engaging position, which is when the signal is displaying its most restrictive aspect. When in this position the trip arm will engage a trip cock located on the main air line on the cars, thus causing an emergency application of the brakes of the train which passes the stop. A push-button switch within reach of the motorman's cab is provided at each automatic stop, which is used to clear the trip arm when it is necessary for a train to pass a "stop" signal.

FIG. 58.



Automatic train stop.

The automatic stop is of the electro-pneumatic type (Fig. 58). Its operation is positive and in event of failure of electric or pneumatic power the trip arm assumes the engaging position, thus making the signal system safe.

Track Circuits.—All track circuits are a full block long except where cut sections are required and within interlocking plant limits. Alternating current is supplied at one end of each track circuit, the limits of which are established by insulated joints in the rails, by a 14-volt air-cooled transformer equipped with taps to permit fine voltage adjustment. The track relay is of the two-element, two-position vane type.

Track connections are made through cables buried in the concrete with leads connected to the rail lugs of impedance bonds. On double rail track circuit sections impedance bonds with an iron core are provided to carry the propulsion current around the insulated rail joints. These bonds have a continuous carrying capacity per rail of 750 amperes, 2000 amperes for ten minutes, or 5000 amperes for one minute. To avoid the use of a large number of impedance bonds on short track circuits at the large interlocking plants and in the terminal yard, only one rail is used for the propulsion current and the other is bonded and insulated for the signal track circuit.

Signal control apparatus is housed in cast-iron boxes of 2-, 4-, 6-, or 12-relay capacity located in the vicinity of the signal, controlled and connected to it by conductor cable in galvanized conduit. Signal control cables are run in a three-way duct bench on both sides of the subway.

Switch Operating Mechanism in the Subway.—The switch operating mechanisms are of the electro-pneumatic type with electrically operated cut-off valves. Their operation is positive and a movement from normal to reverse can be made in 1½ seconds with air pressure as low as 75 per cent. of normal. A means of operating them by hand is provided for emergency. (Fig. 59.)

Compressed Air Equipment.—Compressor plants are located at Fairmount Avenue, Erie Avenue, Olney Avenue, and the terminal yard portal, each having a capacity of 75 cu. ft. of air per minute, excepting the one at the yard, which has a capacity of 100 cu. ft. per minute. All of these compressors are in duplicate and are driven by D.C. series wound motors designed to operate from the 630-volt contact rail circuit. Each plant is equipped with condensers, main reservoir, and switch panel containing a watthour meter, ammeter, voltmeter, air-pressure gauge and various switches.

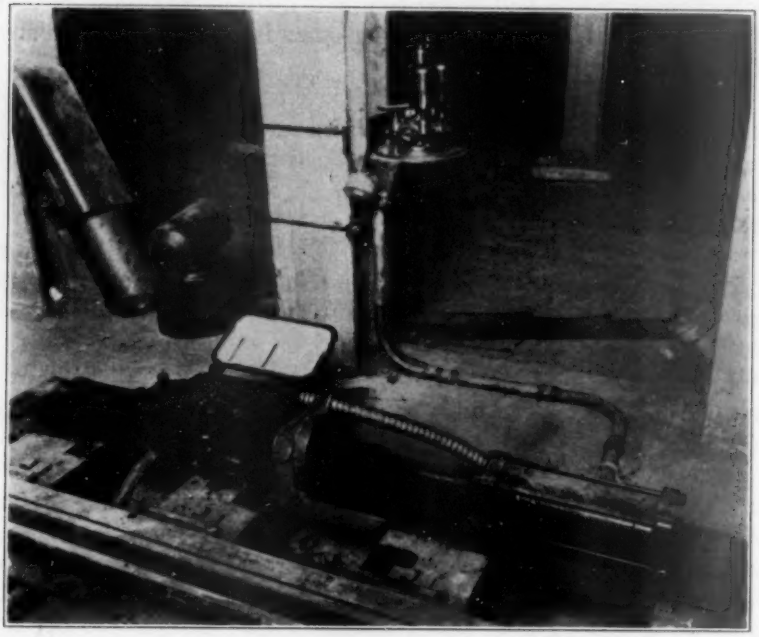
Interlocking Stations.—The interlocking machines are located at five stations along the line and at the yard portal. They are power machines and range in size from 7 levers to 75 levers. All of the machines, with the exception of that at City Hall, which is temporary, have been provided with sufficient spare space for ultimate four-track operation.

The position of trains is indicated to the towerman on a

track model, located directly above the machine, by means of spot lights marking the sections of track within the plant limits and adjacent thereto.

Mechanical locking is used in the machines and in addition to the mechanical locking, routes are controlled, interlocking levers are locked, and switches are locked electrically by a train in a given track circuit.

FIG. 59.



Electro-pneumatic switch operating mechanism.

Terminal Yard Equipment.—In the terminal yard the track switches are electro-pneumatically operated and controlled from a tower in the yard entrance building. The switch mechanisms are not interlocked and depend upon air pressure to keep them in position. The control panel is equipped with spot-light indicators above each lever. Electrically lighted switch signals are provided to indicate the position of the switch and are controlled by a circuit controller which operates with the switch points.

The wiring for the various controls is carried throughout the yard in treated trunking supported every seven feet on concrete

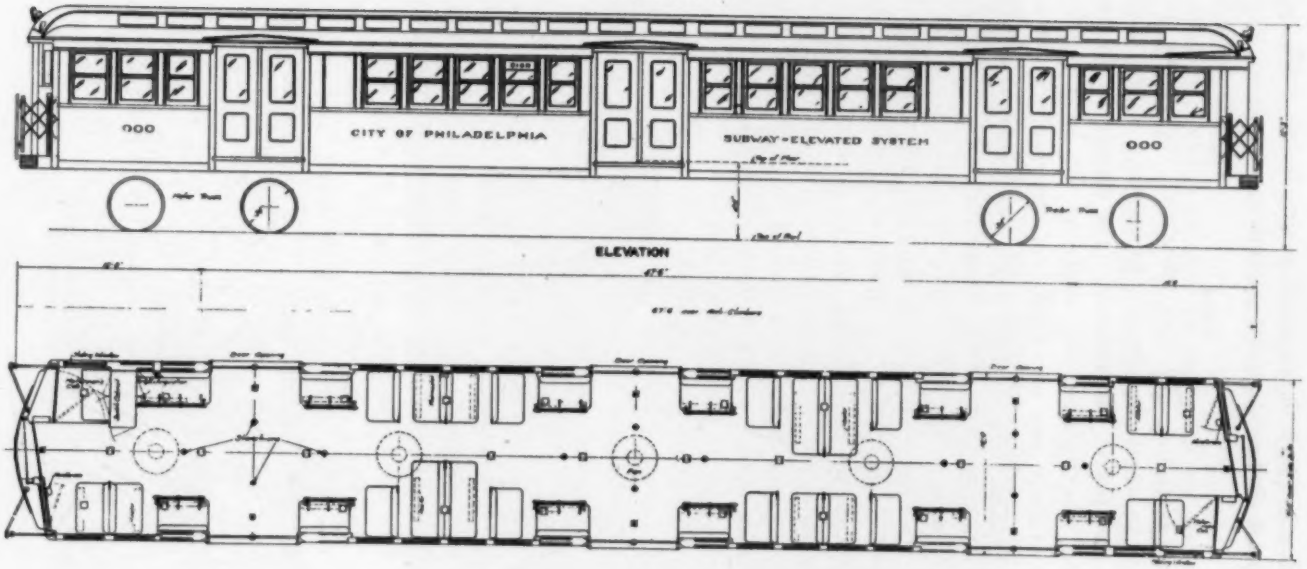
piers, which also carry the two-inch main air line. All apparatus is of the latest design for yard operation.

CARS.

Aims of Design.—The 150 passenger cars being provided are designed to assure safety and to enable a superior standard of service and public convenience. The design is the result of an extended investigation and study of the local requirements and of car practice and experience on other subway or elevated systems, railroads and street railways, and a balancing of factors, such as seating capacity and arrangement, door capacity and arrangement, ease of movement between platform and seat, speed of loading and unloading, safety of passengers and crew, utilization of track capacity, etc., with due consideration of the effect of these features on the costs of investment and operation. The trend of practice and our investigations pointed towards the use of large cars, giving greater freedom in arranging convenient seating, fewer units, and lower costs per passenger carried, for crew, for power, and for maintenance.

Seating and Door Arrangement.—As shown in Fig. 60, the car is 67½ feet long and 10 feet wide. On each side it has three double leaf doors, of ample size and evenly spaced relative to seats and spaces inside the car and relative to platform crowds on its exterior. The distance between side doors is 16 feet. Operating cabs are placed in diagonally opposite corners at each end, and end doors enable communication between cars. The absence of end platforms of any description is to be noted, as is also the extended use of cross-seats. There are seventy-five seats, of which fifty are cross-seats, arranged to give ample reservoir space near the doors, easy access to and from the seats and to and from the doors, with ample knee room, and an absence of narrow aisles and of facing seats. The total capacity of the car, on the basis of the usual rating of 2 sq. ft. of free floor space per standee, is 212, as compared with 134 and 152 on the Market Street subway and Frankford elevated cars, respectively. The latter cars have only longitudinal seats. These features also help to give the car flexibility and adaptability to meet the fluctuation in load which will inevitably be imposed in operation, regardless of the standard of loading contemplated.

FIG. 60.



Broad Street subway passenger car—plan and elevation.

Interior Features.—A number of the interior features are shown in Fig. 61. The seats are the stationary spring cushion type, covered with rattan. Hand grabs on the ends of the cross-seats, hand straps suspended from the roof in front of the longitudinal seats, and stanchions located in front of the door openings will add to the comfort of the riders. Ventilation is provided for by means of adjustable shutters in the monitor sides, drop

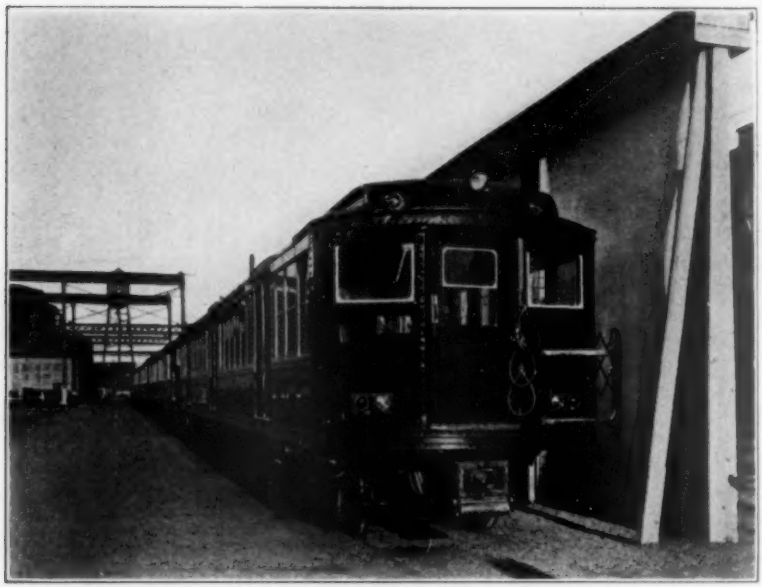
FIG. 61.

Interior view of subway car.

sash in the upper half of the windows, by panels in the end doors, and by five electric ceiling fans. Electric heaters are placed under the seats and are thermostatically controlled. The regular lighting system consists of twenty-two ceiling lights, 45-watt series units, arranged in three rows along the centre and on either side of the car. Low-voltage emergency lighting units placed over each of the doors are supplied from a storage battery and are automatically lighted whenever the power supply from the main lighting units is interrupted or fails. Ample lighting, a white ceiling, and relatively light-colored side walls contribute to a cheerful looking interior.

Door Control.—The side doors are opened and closed by pneumatic equipment, electrically controlled from one of the cabs. In coöperation with the manufacturer, an arrangement has been developed enabling either single or multiple control of doors, depending upon the setting of a master switch in each cab. From an operating position in any one of the cabs, the doors on the same side of that car and of other cars to either side can be

FIG. 62.



Exterior view of subway car showing automatic coupler and safety gates.

opened and closed by manipulating two tumbler switches. Red lights on the exterior of the car body are lighted if any door on that car is open, and a signal light in the motorman's cab shines *only* when all doors on the train are closed. Another special device enables the motorman, for example in case of overrunning a station platform, to nullify the door-operating circuits, preventing the guards from opening the doors, or if they have already been opened, closing them automatically. Push buttons on the outside of the car will enable platform men to close individual doors; key switches on the centre doors will enable the operating force to pass in or out easily when alone, and in case of failure

of air or electric supply, certain of the doors can be opened mechanically from the inside, and one of them from the roadbed. Considering the number of functions, the equipment as developed is relatively simple and largely composed of units tried out in similar services. The current necessary for operating the various relays, magnet valves, etc., is supplied by the same storage battery that supplies emergency lights, tail and marker lights, and other control circuits. All circuits—except those to the main motors—

FIG. 63.

Motor truck—side view.

are fused and controlled at two switchboard panels built into the cab walls.

Couplers, Trucks, Motors and Motor Control.—Passing to the exterior of the car, shown in Fig. 62, attention is directed to the fact that the guards do not "ride the bumpers" but operate from the cabs, which are equipped with special windows, grab handles, etc. Automatic couplers designed to couple the cars, the air lines and the electric train operating circuits, all of which are low-voltage circuits, have been installed. These couplers, together with the automatic safety gates between the cars and the arrangement and location of controls, will enable coupling and uncoupling to be performed from a position in the motorman's cab on either side of the connection with the minimum labor and hazard. Coupling and uncoupling can also be performed from a position on the roadbed alongside of the car.

The trucks are four-wheeled, of the M.C.B. equalizing type, a motor truck and a trailer truck under each car, spaced 47 feet 6-inch centres, giving a 10-foot end overhang.

The truck frames are one-piece steel castings, the wheels are solid rolled steel, and the bearings for the 5½ × 10 journals are solid bronze of the A R E A type. Six of the cars are being equipped with roller bearings.

The motor truck (Figs. 63 and 64) is equipped with two 210-h.p., 600-volt, field-control, axle-hung motors, driving through helical pinions and gears. A distinctive feature of the motors is the " dual " system of ventilation. One current of air

FIG. 64.

Motor truck—top view.

enters the armature bearing housing at the commutator end, passes under the commutator, through the armature core longitudinally, and out through the fan at the back end of the motor. The other air current enters through openings in the frame back of the commutator, which is baffled from this air, through the air gap and between the field coils, and through the double-bladed fan and out at the back end. Thus none of the air passes over the commutator, and troubles due to dirt and brake shoe dust are avoided, and the wear of the brushes is decreased.

Both the motors and the control equipment have been designed and built especially to enable rapid acceleration, rapid braking,

short stops, and high-schedule speeds, under the severe conditions of subway rapid transit service. The presence of considerable brake shoe dust in subways adds to the difficulties of meeting the requirements.

Multiple-unit control, of the unit-switch type, has been provided. A train can be operated from a master controller in any cab. The operation of the master controller establishes circuits through the train which cause the automatic operation of the main motor controls located on every car of the train. An air-operated sequence switch which actuates ten main motor control switches of the "unit" type, so called because each one is a complete unit consisting of contacts or jaws, shunt, blow-out coil, air cylinder, and an electrically operated air valve, produces the automatic acceleration.

A safety feature is the so-called "dead man's handle," a device which automatically cuts off the power and causes an emergency application of the brakes if the motorman should become incapacitated while his controller handle is in any position other than "neutral." All trucks are equipped with clasp brakes, operated both mechanically and pneumatically from the same position of the operating handle, emergency application, and all other modern devices making for safety, positiveness of operation, and smoothness of braking.

Lightness—to the extent consistent with stiffness, safety and low maintenance—is an obvious advantage and considered to justify very careful design. The completed car, including all equipment, weighs 104,700 lb. An interesting structural feature of the car is the extended use of pressed-steel parts in the framing and the diagonal bracing carried through the full length of the underframe to strengthen it against buckling loads.

The motors, motor-control equipment, air-brake-operating equipment, door-operating equipment, automatic couplers, and roller bearings were bought under separate contracts requiring delivery to the car builder for assembling, mounting and adjusting on the cars. The cars, including all equipment, will cost a little less than $40,000 per car.

Smoke Studies. (United States Public Health Service.)—Smoke in the atmosphere, especially when combined with mist to produce fog, brings about a very great lowering of the daylight. At the present time a great loss of light results in large cities from the effect of smoke. A study of the decrease of light by smoke, now being made by the U. S. Public Health Service in New York City, at the lower end of Manhattan Island where the air is very smoky, showed an average loss of daylight due to smoke in January of 1927, on sunny days, of 42 per cent. at 8 o'clock in the morning, and of 18 per cent. at noon. These amounts of loss of daylight decreased, as the year advanced, to 33 per cent. at 8 A.M., and 6 per cent. at noon, in June. These figures are for clear sunny days; for foggy days, the loss is much greater. The loss of light due to smoke in the atmosphere is greatest early in the morning or late in the afternoon, and least at noon. As would be expected, the loss of light is greater in the winter than in the summer. The figures given show the great importance of getting rid of smoke in our great cities. Loss of daylight or the light rays is not the only evil resulting from the presence of smoke in the atmosphere; smoke also cuts out to a much greater extent the ultra-violet rays which are so necessary for good health.

The amount of light reaching us at different times of the day, at different times of the year, and under different conditions of weather is of interest. Illumination is measured in a unit called the foot-candle, one foot-candle being the illumination on a surface at a distance of one foot from a standard candle. Records of daylight in Washington, D. C., have been made since July, 1924, by the U. S. Public Health Service. These records show that at noon on a bright day in midsummer the illumination seldom exceeds ten thousand foot-candles. In mid-winter at noon on a bright day it seldom exceeds 3500 foot-candles. The difference in illumination on sunny and cloudy days is illustrated by the average illumination for such days in December, 1924, and in June, 1925. In December the average illumination on cloudy days was found to be about 23 per cent. of that on sunny days. In June this ratio was about 26 per cent. Great variations in daylight take place when small clouds pass over the face of the sun on a clear day. In such cases the light may fall from 9000, or more, foot-candles to 3000, or less, in one minute's time, and return to the original amount during the succeeding minute.

Large increases of light may be produced by the reflection of light from banks of white clouds to the north of the sun, and very great decreases by the heavy clouds of thunderstorms.

Sunlight is of great interest and importance, since work in the office, shop, schoolroom or on the farm is performed under it; and the preservation of eyesight, the general health, and the prevention of accidents, throughout childhood and adult life, are largely dependent upon having plenty of sunlight both inside and outside the buildings in which we live and work.

A MERCURY VAPOR TRAP OF LOW RESISTANCE.

BY

THOMAS H. JOHNSON, Ph.D.

Bartol Research Fellow.

BARTOL RESEARCH FOUNDATION
Communication No. 20.

THE resistance of a tube to the flow of gases at low pressure is given, according to Knudsen's Law, by

$$W = 1.59 \times 10^{-5} \sqrt{M} \sqrt{\frac{273}{T}} \frac{l}{D^3}, \qquad (1)$$

where M = molecular weight of the gas,
l = length of the tube,
D = diameter of the tube,
T = absolute temperature of the tube.

The velocity of a pumping system composed of a pump of velocity S and a tube of resistance W is given by S', where

$$\frac{1}{S'} = \frac{1}{S} + W. \qquad (2)$$

The importance of using short tubes of large diameter, where the full advantage of a high-velocity pump is desired, may be realized from the following example: Let S = 10,000 c.c. per sec., *i.e.*, approximately the velocity of a Gaede Steel Diffusion Pump, and suppose a tube 3 cm. in diameter and 48 cm. long is joined in series with the pump; the resistance of such a tube for air is, from (1),

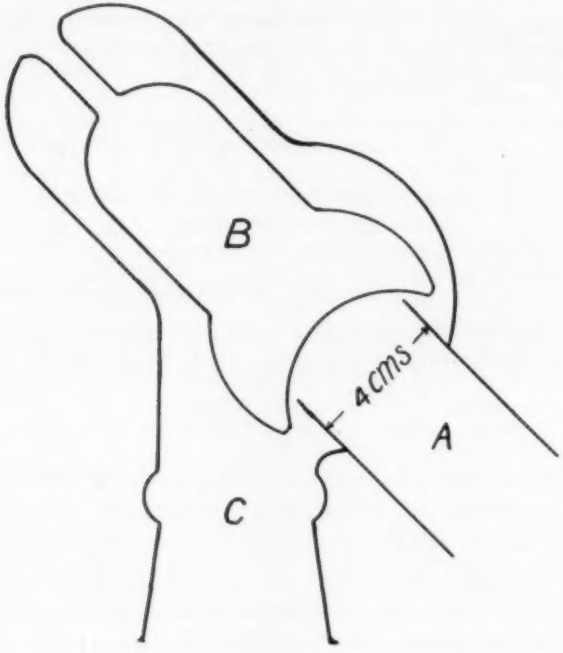
$$W = \frac{1}{10{,}000} \frac{1}{\text{c.c. per sec.}}$$

Then according to (2) S' = 5000 c.c. per sec., and the velocity of the system is only one-half of the velocity of the pump alone.

It is apparent, therefore, that the ordinary type of mercury vapor trap, unless it be made from very large tubes, may seriously reduce the pumping velocity. Where high-velocity pumping is demanded, the mercury vapor trap shown in Fig. 1 has been found to give satisfactory results both in eliminating mercury vapor and in rapidly conducting the gas. The tube A, which leads from the vessel to be evacuated, has its open end com-

pletely surrounded by the cup-shaped surface of the bulb *B*, which is filled with liquid air. No mercury molecules can pass into *A* from the tube *C* which joins to the pump, unless they are reflected from the cold surface or unless they make collisions with other molecules within the cup. It will be seen presently

FIG. 1.



that neither of these causes allows an appreciable amount of mercury vapor to pass the trap.

The form of the trap shown in Fig. 1 is that which has been used with a Gaede Steel Diffusion Pump. The bulb *B* is inclined at about 45° with the vertical tube *C* so that mercury which drips from *B* falls back into the pump. The dimensions of this trap as indicated in the figure are such that the trap offers a very slight resistance to the flow of gas.

Although no rigorous tests have been made as to the effectiveness of this particular trap in eliminating mercury vapor, such tests were carried out on another slightly smaller trap of similar design which was used in conjunction with a glass diffusion

pump. With this trap the pressure of mercury vapor was less than 10^{-6} mm. as measured by an ionization gauge and no change in pressure was observed when a second trap of the usual design, which was joined in series, was immersed in liquid air.

The mercury coating which forms on the bulb *B* acts as an effective radiation shield so that liquid air will remain in the bulb for three or four hours without replenishing.

A New Determination of the Half-value Period of Proto-actinium. OTTO HAHN and E. WALLING. (*Naturwissenschaften*, Sept. 30, 1927.)—Proto-actinium with its three isotopes has the atomic number 91 and has for neighbors in the table of the elements thorium, 90, and uranium, 92. It merits particular interest because it shares with radium the distinction of being a radio-active element that requires a long time to become spontaneously transformed to the extent of half its mass into another element, and, therefore, of occurring on the earth in not too small quantities. Hann and Meitner some years ago found its half-value period to be about 12,000 years. In the present determination uranium nitrate was carefully freed from proto-actinium and placed aside for as much as four years so that this element might develop by radio-active processes. From four independent experiments supplemented by two of less value the half-value period is set at 20,000 years with a possible error of 10 per cent. A metric ton of uranium after it has reached a state of radio-active equilibrium with its progeny will contain 129 milligrams of proto-actinium. A ton of the residue from the Joachimsthal mines contains 185 mg. of this element.

G. F. S.

IN *Nature* (Nov. 5) is given the address on "Study and Research in Physics" delivered by Sir Ernest Rutherford at the opening of the Henry Herbert Wills Physics Laboratory of the University of Bristol. He emphasized the importance of research conducted for the extension of knowledge and without apparent direct relation to industrial problems. For illustration he employed the results that have followed from the study of the interesting but seemingly unimportant discharge of a gold-leaf electroscope when X-rays traverse the adjacent air. On the theoretical side came the discovery of the electron and the development of methods for investigating radio-activity and on the practical side the transmission of pictures to a distance, electric oscillators and receivers used in radio transmission. "Apart from the interest and importance of adding to our knowledge of the processes of Nature, experience has shown that discoveries of the greatest significance to mankind, whether in the practical or intellectual sphere, are generally the outcome of fundamental research undertaken purely with the aim of adding to knowledge."

In the course of his discussion of the action of ionized gases he says, "I must also particularly mention the researches in recent years on the life-history of an ion, the avidity with which it seizes on the molecules of water added to a dry gas, and the still greater avidity for the heavy molecules of alcohol and the consequent sluggish movements of the loaded ion. On this aspect of the almost human behavior of the gaseous ion, the researches of Professor Tyndall and his students have given us most valuable information."

G. F. S.

LOW-PRESSURE ELECTRIC DISCHARGE.

BY

C. DEL ROSARIO, M.S.

Bartol Research Fellow.

INTRODUCTION.

BARTOL RESEARCH FOUNDATION
Communication No. 21.

AT THE Philadelphia meeting of the American Physical Society in December of 1926, the writer reported experiments on the currents produced between a cylinder and a concentric platinum filament 5×10^{-4} cm. in diameter. A more detailed account of these experiments was subsequently published in the February, 1927, number of this JOURNAL. It was found that with a field of 2×10^{6} volts per cm. at the surface of the filament, the current obtained in a vacuum of the order of 10^{-8} mm. Hg was less than 0.5×10^{-10} ampere. When air was admitted to a very slight extent, this current was greatly increased and reproducible current-voltage curves were obtained.

As results of preliminary experiments with wires of different sizes, it was surmised at the time that the current to be obtained from a filament under the conditions of the experiment was determined by the potential difference between the cylinder and the filament rather than by the field at the surface of the filament. This would explain the fact that others who used smaller fields but thicker wires obtained larger currents, because in order to realize those fields it had been necessary to use higher potential differences.

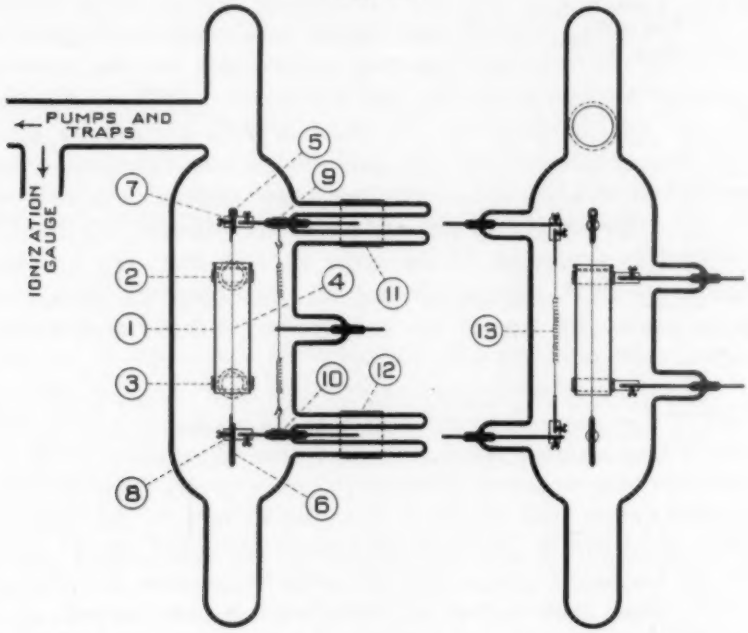
EXPERIMENTAL METHODS.

The experiment now to be described has extended the previous observations to four different sizes of wires ranging from 16×10^{-4} to 53×10^{-4} cm., with the result that the conclusion as to the dependence of the current upon the potential difference rather than the field has been strongly confirmed.

The apparatus used in the investigation presents several improvements over the one previously used. Among these are the visibility of the entire filament and the inside surface of the cylinder, and the possibility of more completely outgassing the

metal parts. Fig. 1 shows two sections of the experimental tube. The nickel cylinder (1) is held by collars, (2) and (3), which are screwed on to tungsten leads as shown. The tungsten filament (4) is welded to two small nickel rods, (5) and (6), which rest in holes in bigger rods, (7) and (8), respectively. It can be readily seen that the filament has a freedom of motion in the plane containing the filament leads, while the cylinder has one in a perpen-

FIG. 1.



dicular plane through the cylinder leads. This feature renders it possible to make them accurately concentric. The coils of fine copper, (9) and (10), around the filament leads and the tin foils, (11) and (12), are all grounded and serve as guard rings to eliminate any leakage current through the glass from the high-potential cylinder leads to the filament leads. The filament may be removed and a new one put in through the top of the pyrex glass tube which can be readily blown out. The whole operation involves only the use of the small screws on the ends of rods, (7) and (8), and therefore does not disturb any previous adjustment.

Extreme care was taken in cleaning all the parts of the apparatus, especially with regard to the elimination of alkaline impurities and grease. Chromic acid, aqua regia and distilled water were used for the glass parts and the tungsten filament. Alcohol was used for the other metal parts, and all parts were subsequently always handled with gloves. The experimental tube, the ionization gauge, and the two liquid-air traps in series were preliminarily outgassed in a hot-wire furnace at 400° C. for five hours. Then the liquid-air trap farther away from the tube was immersed in liquid air while the rest was baked for another five hours, at the end of which time the liquid air was transferred to the other trap—nearer the tube. The preliminary baking without liquid air serves to remove condensible material from the system and prevent its accumulation in the liquid-air traps where even at liquid-air temperature it may give rise to appreciable vapor pressure. The use of two liquid-air traps in the above way minimizes the diffusion of mercury vapor into the experimental tube. The cylinder was further outgassed by electronic bombardment from the tungsten spiral, (13). More complete outgassing of the filament could be effected by passing a current through it, and its temperature was calculated from Langmeir's [1] data, using the measured diameter and the current flowing.

All measurements were made in vacuum of the order of 10^{-8} mm. Hg produced by two double-stage Kurth mercury diffusion pumps in series and backed up by a Cenco Hyvac oil pump. It should be noted that while a McLeod gauge was put in the vacuum system, it was only to detect large leaks or rapid evolution of gases from the glass and metal parts. All tests of the degree of vacuum rested ultimately on the ionization gauge, which is of course sensitive to condensible vapors which would not record on the McLeod gauge. Nevertheless, it is of interest to remark that the McLeod gauge would sometimes show a "negative" pressure of 250 mm. Hg (a mercury column of 250 mm. hanging from the top of the 0.8-mm. capillary), while the pumps were going, and a "negative" pressure of 20 mm. a day after the tube, gauges and traps have been cut off from the pumps. The ionization gauge was of the Dushman-Found [2] type, where the inner coil was made the source of electrons and

[1] *Phys. Rev.*, **7**, 315, 1916.
[2] *Phys. Rev.*, **17**, 7, 1921.

the cylinder the collector of positive ions. The constant k which appears in the formula $p = kI_i/I_e$ was taken to be 0.23—p being the pressure in mm. Hg and I_i and I_e, the positive ion current and electron current, respectively, being expressed in the same unit. In using the ionization gauge it is desirable that the temperature of the hot filament be not too high, as otherwise the vapor pressure of the tungsten becomes appreciable. This temperature was never allowed to exceed 2300° K., so that the vapor pressure of tungsten was always less than 10^{-10} mm. Hg during the pressure measurements.

The high potential was obtained from a transformer and kenotron set with smoothing condensers which reduced the voltage ripples to less than 1 per cent. for the worst case, *i.e.*, when the maximum current was being drawn. The positive terminal was connected across a water resistance of about 10^4 ohms, to the cylinder through the upper tungsten lead, while the lower lead was connected to an improved Braun electrostatic voltmeter. This arrangement eliminated the possibility, due to bad contacts, of the existence of voltages at the cylinder different from that measured with the voltmeter. The filament was grounded through a sensitive galvanometer or through a Rawson multimeter in case of higher currents. The variable galvanometer shunt and the wide-range multimeter made it possible to measure currents in a continuous range from 10^{-10} amp. to 5×10^{-4} amp., which is the maximum used.

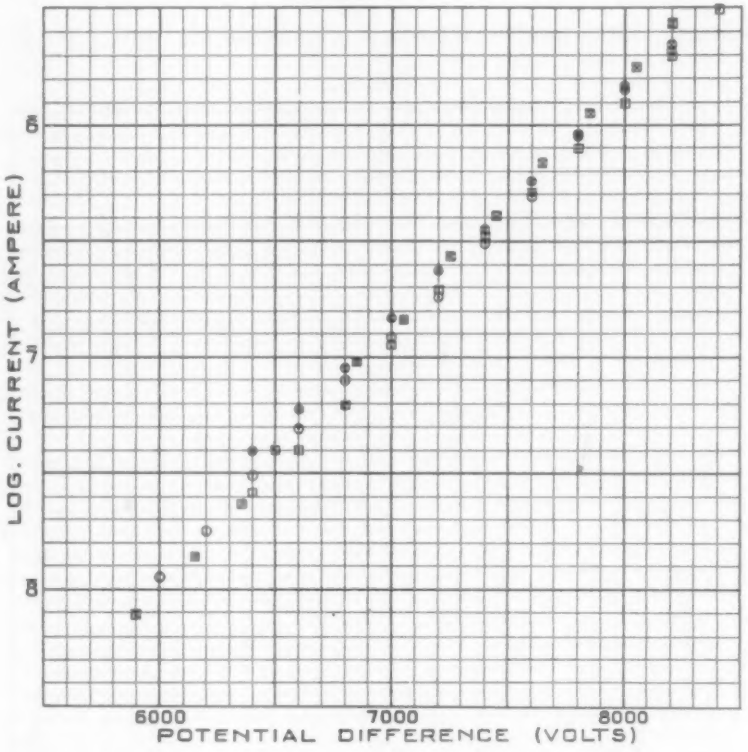
DISCUSSION OF RESULTS.

An interesting result also noted by some previous observers and of particular importance in the present experiments is that after the current reaches a given value the log current-voltage curve, subsequently obtained, will always retrace itself provided that this given current is not exceeded. If it is exceeded, a new retraceable curve is obtained which is parallel to the first but displaced towards higher voltages. In the experiments for the comparison of results with different wires, care was taken to insure that the maximum current was the same for all of the wires in addition to that taken to treat them as far as possible alike in the matter of outgassing, etc.

It was shown that under these conditions the currents obtained depend upon the voltage rather than the field. This can best be shown by plotting the results of experiments with different wires

on the same graph. (Fig. 2.) The points represented by ⊡, ⊠, ⊙, and ⊗ are for wires .0016, .0028, .0045 and .0053 cm. in diameter, respectively, all of which have been outgassed at 400° C. for ten hours. The maximum current in each case was

FIG. 2.



5×10^{-4} amp. The points for the different wires fall on the same curve almost as well as do the points from one wire.

The field E at the surface of the wire is given in terms of the potential difference V, the radius R of the cylinder and the radius r of the wire by the relation

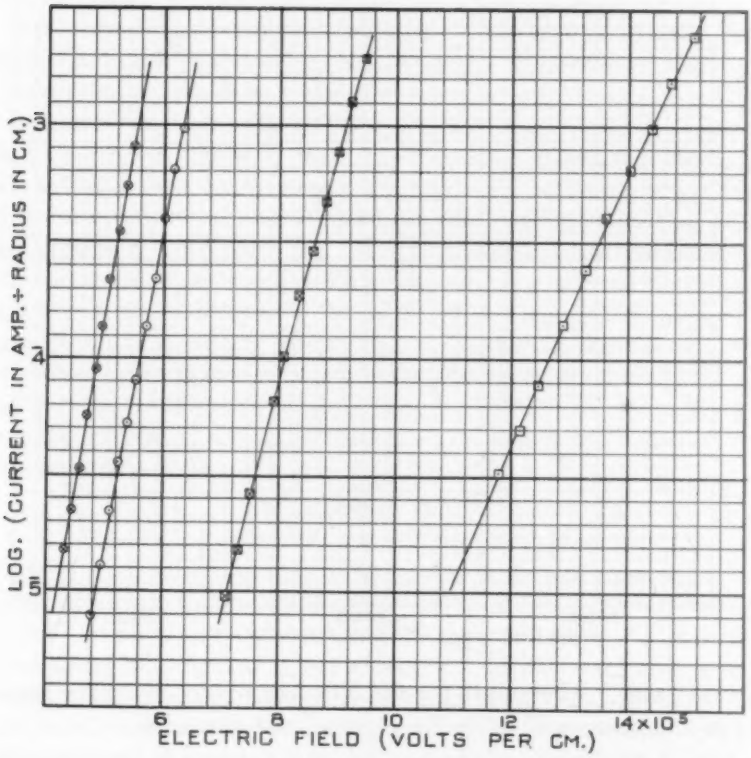
$$E = \frac{V}{r \log \frac{R}{r}}. \qquad (1)$$

Hence, if the current density depended entirely upon the field intensity at the surface, we should have

$$\frac{i}{r} = f(E)$$

where i is the current. Fig. 3 gives the values of $\log \frac{i}{r}$ for the different wires plotted against E as calculated from (1), and

FIG. 3.



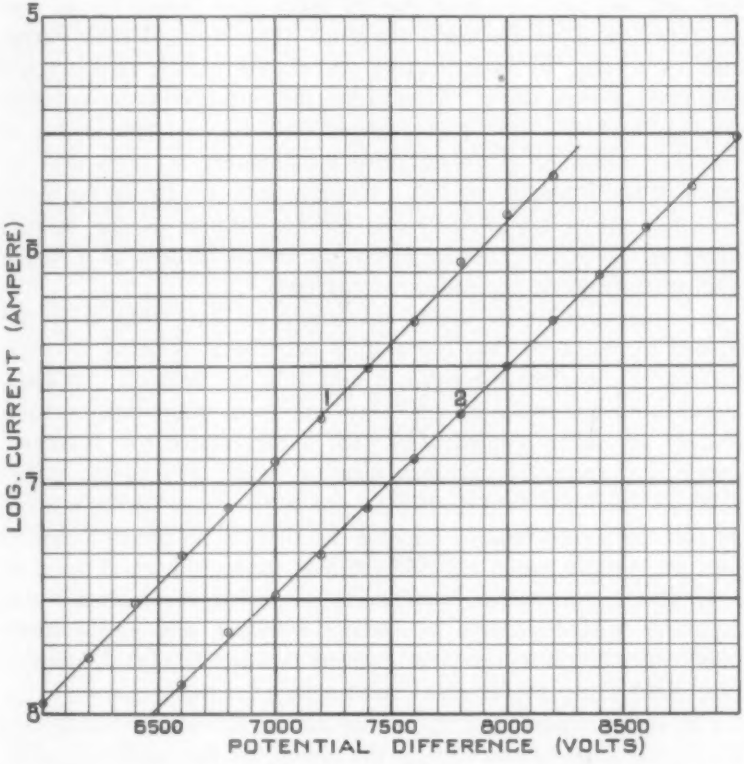
it will readily be seen that the results for different wires fall on different curves, showing quite definitely that in these experiments the current is not a function of the field alone.

Fig. 4 shows the effect of more complete outgassing of the filament. Curve 1 corresponds to a filament baked simply in a hot-wire furnace at 400° C. for ten hours. Curve 2 is for the

same wire after it has been heated to 1400° C. for five minutes. It has been observed that the more complete the outgassing of the filament, the farther the curve is displaced towards higher voltages with only a slight decrease of slope.

Curves obtained while the filament is being heated show no appreciable effect due to temperature until thermionic emission

FIG. 4.



becomes appreciable. This is in agreement with results of some former experimenters. Beyond this stage the current becomes unsteady, but it is quite apparent that the total current is simply the sum of the "cold" current and the thermionic current.

It has been observed in these experiments as well as by former investigators that when current is flowing between the wire and the cylinder, flashes of bluish light appear on the filament. These were sufficiently infrequent, except for large currents, so that each

flash could be recorded separately, and it becomes of interest to see whether the sudden spurts of current associated with these flashes were capable of accounting for an average current comparable with the total current. In order to test this the filament was connected to a fibre electroscope which was grounded through a resistance sufficiently high to show the kicks to practically their full amount. The sudden kick of the fibre at each flash was noted and the total current due to them was found to be less than 3 per cent. of the total current. The light flashes correspond, of course, to local heating associated with a temperature which gives visible light. This raises the question as to whether there may not be a very much larger frequency of spurts due to thermionic emission at an effective temperature so high that its light is in the invisible region. Experiments are being designed to test this point, and also to test the importance of the X-rays emitted by the cylinder under electronic bombardment as a factor in the production of the observed currents.

In conclusion, it is hardly necessary to state that it is not intended to maintain that the simple functional relation between current and potential difference would hold for wires of all sizes. A departure must make its appearance at some stage before inner cylinders of radius comparable with a centimetre are involved. Neither is it intended to imply that at fields very much higher than those used, the field itself may not be the main factor responsible for the production of current density. The present experiments are simply taken to indicate that under the conditions of the present experiments—conditions in which the vacuum was comparable with that used by former workers, and of the order of 10^{-6} mm. of mercury—the current density is not a function of the field alone for a given treatment of wire.

The writer wishes to express his thanks to Doctor Swann for his valuable suggestions during the course of the work.

NOTE ON A TENTATIVE HYPOTHESIS OF THE LATENT IMAGE. II.*†§

BY

A. P. H. TRIVELLI.

INTRODUCTION.

In the paper preceding this [1] the idea was put forward that the formation of the latent image may be directly correlated with the phenomenon of photo-conductivity, whereas the photo-electric effect of Hallwachs plays no important part. This assumption was supported by the fact that immediately, without the introduction of new hypotheses, a qualitative explanation could be given of the general behavior of the intermittency effect and of the failure of the reciprocity law. However, according to Wilson [2] the Hallwachs' photo-electric effect and the photo-conductivity are both in essence the same, the difference lying in the velocity of the liberated photo-electrons. For the theory of the latent image the slow-moving electrons, which do the work of photo-electrolysis, are of most importance, forming around a speck, as electrode, additional silver as a nucleus for development.

This hypothesis left unanswered the fundamental question, as to how the elementary photo-electric current runs, which current, according to the requirements of the electrical theory of Maxwell, should be solenoidal.

SENSITIVITY.

Baker, as early as 1892,[3] showed that *pure* silver chloride does not change at all in light.

Weigert,[4] through his experimental investigations, came to

* Communication No. 313 from the Kodak Research Laboratories.

† Presented in abstract at the Detroit meeting of the Am. Chem. Soc., Sept. 10, 1927.

§ Since the present paper went to press a note by F. C. Toy appeared (*Nature*, Sept. 24, 1927, p. 441) which also sets forth a hypothesis of the latent image based on the photo-conductive property of the silver halides and of silver sulphide. One of the difficulties in the photo-electric conduction theory of the latent image has been the wave-length effect which has now been removed by the valuable work of Doctor Toy.

[1] Jour. Frank. Inst., **204**, 649, November (1927).

[2] W. Wilson, *Ann. d. Phys.*, **23**, 107 (1907).

[3] H. B. Baker, *Jour. Chem. Soc.*, **61**, 728 (1892).

[4] F. Weigert, *Sitz. Ber. Preuss. Akad. Wiss.*, 641, July (1921).

the same conclusions, and regarded a silver speck in the silver halide as an autosensitizer. Even before this, Lüppo-Cramer [5] as a consequence of the results of his treatment of ripened photographic plates with chromic acid solutions previous to exposure, concluded that during ripening a slight reduction of silver halide takes place, producing minute traces of colloidal silver, thus supporting Eder's hypothesis that the high sensitive photographic plates contain " Reifungskeime."

Renwick [6] said, " Considerations of these and other aspects of the problem have led me to the conclusion that in our most highly sensitive photographic plates we are dealing with crystalline silver bromide in which besides gelatin some highly unstable form of colloidal silver exists in solid solution, and *that it is this dissolved silver which first undergoes change on exposure to light.* If this be so, it is clear that it is the function of the ripening process to produce this colloidal silver in the grains of the emulsion in the most sensitive (resonant) form, while avoiding any means which might bring about its precipitation in the gel form—the gel or electrically neutral form of colloidal silver being regarded as the germ or catalyst required to promote development."

In a previous paper [7] the question was discussed as to why we have to regard the latent image as minute amicroscopic specks distributed over the surface of the silver halide grains and why the formation of the latent image is considered to be intimately connected with the sensitivity, which in turn is believed to be due to the presence of still smaller specks having the same distribution.

An entirely new phase in the evolution of theories about the formation of the latent image was introduced by Sheppard [8] through his discovery of the action of traces of allylthiourea in gelatin on the sensitivity of photographic emulsions. He was able to give very strong evidence for the formation of minute

[5] Lüppo-Cramer, *Phot. Mitteill*, 328 (1909).

[6] F. F. Renwick, *J. Soc. Chem. Ind.*, **39**, 156T (1920).

[7] S. E. Sheppard, A. P. H. Trivelli and R. P. Loveland, JOUR. FRANK. INST., **200**, 51 (1925).

[8] S. E. Sheppard, *Coll. Symp. Monogr.*, **3**, 76 (1925); *Phot. J.*, **65**, 380 (1925).

specks of silver sulphide on the silver halide grains, which specks, it was postulated, increase the sensitivity by serving as concentration points for latent image formation.[9] The silver "Reifungskeime" of the "silver germ" theory of sensitivity were replaced by the silver sulphide nuclei of the "concentration speck theory." In other words, it was regarded that the function of the silver sulphide specks was to serve as the centres around which the photochemically liberated silver atoms or ions might collect.

E. P. Wightman and R. F. Quirk, at the American Chemical Society meeting, September, 1926, stated [10] in their second paper on "Intensification of the Latent Image on Photographic Plates and Films" that they believed that the sensitivity spots contain some Ag in addition to the Ag_2S.

Clark's independent experiments [11] on the action of oxidizers on the sensitivity and latent image of high-speed plates and on colloidal silver sulphide in gelatin, support this view of Wightman and Quirk. He states, "It appears, then, that the results obtained could be explained on the view that silver sulphide is present in the sensitivity substance, provided it is postulated that there is also present something—say, silver—which is attackable by oxidizers of potential too low to attack silver sulphide. There is, of course, no sure ground for postulating either of these two substances, but Sheppard's results indicate the possibility of the presence of silver sulphide, and the view has long been held that the sensitivity is due to silver itself. If both are present the older and the newer theories can perhaps be reconciled."

THE ELEMENTARY PHOTO-ELECTRIC CURRENT.

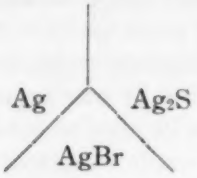
Assuming that the explanations of Wightman and Quirk as to the action of hydrogen peroxide on high sensitive plates and of Clark as to the action of oxidizers on similar plates are correct, the former dealing with increase of developability, of the sensitivity, and of the latent image; the latter dealing with decrease in sensitivity, are right, both independently of each other having

[9] S. E. Sheppard, A. P. H. Trivelli and R. P. Loveland, *loc. cit.*

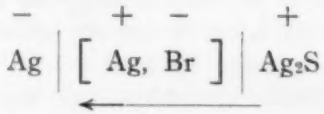
[10] To be published shortly in the JOUR. FRANK. INST.

[11] W. Clark, *B. J.*, 74, 227, 243 (1927).

come to the same conclusion as to the composition of the sensitizing speck, then it is evident that we have to deal with the system



In this system an elementary photo-electric circuit is possible, Ag being the cathode, Ag_2S the anode, and AgBr the solid electrolyte, thus in this cell:



the elementary electric current runs through the AgBr towards the Ag cathode, hence the Ag cations from the AgBr move toward the Ag cathode. The silver speck therefore increases in size until developability is reached.[12]

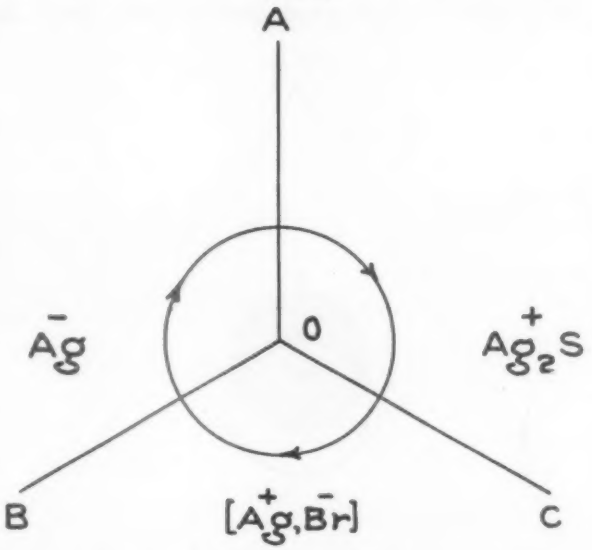
The Probable Way in Which Silver Sulphide and Silver Are Formed in the Sensitizing Speck.—The art of making high sensitive photographic emulsions may be regarded largely as the art of introducing certain impurities into the silver halide in the proper way. Sheppard in his previously mentioned work made it appear probable that silver sulphide specks are formed on the silver bromide crystals through a special sensitizer in the gelatin (allylthiourea). These specks appear to cause an increase not only in speed but also in gamma. The emulsion is kept for a shorter or longer time at a high temperature. During this so-called ripening process not only are the silver sulphide specks formed, but it is quite possible, as indicated above, that a slight reduction of the silver halide to silver takes place. It is likely that this reduction will take place on the weakest spots of the crystal lattice, where, for instance, impurities were introduced previously. Hence we should have the formation of specks of metallic silver at the boundary of silver sulphide and silver halide. It is supposed that as soon as a silver speck is formed in contact

[12] See paper shortly to be published by L. Silberstein in the *Phil. Mag.* on the "Theory of Photographic Exposures."

with the silver sulphide speck on the silver halide crystal surface an increase in sensitivity results.

The Probable Picture of the Elementary Photo-electric Cell that Forms the Latent Image Speck from the Sensitivity Speck.—Turning back to Fig. 1, we see that silver will be deposited along the surface of contact on *OB* and the photo-electric cur-

FIG. 1.



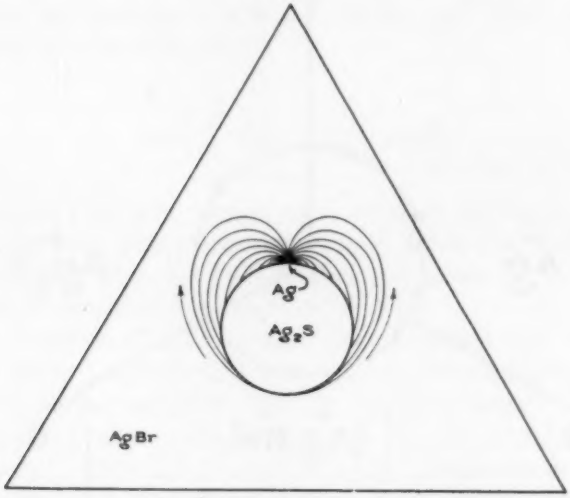
rent will be a maximum near *O* and will decrease in strength the farther we go away from *O*.

If we assume, for the sake of the argument and for illustrative purposes, that the silver sulphide speck has the shape of a disc in the silver bromide crystal and that somewhere attached to it is a semi-circular silver speck extending out over the silver bromide crystal surface, then the photo-electric current will run in the direction shown in Fig. 2. In its passage from the triple point Ag-AgBr-Ag_2S the field of the current takes a cardioid-like shape. The current being strongest at the triple point (the point *O* in Fig. 1), the greatest amount of silver will be deposited there and the silver will show a tendency gradually to envelop the whole silver sulphide speck, thus tending to isolate it from the silver bromide (Fig. 3). This means that the mass of photo-electrically deposited silver depends on the size of the silver

sulphide speck, which is in qualitative agreement with experimental evidence, that with an increasing amount of sensitizer in the gelatin an increasing sensitivity is possible until a certain maximum is reached.

The whole photo-electric current circulates in the system Ag|AgBr|Ag_2S, leaving the gelatin untouched. This agrees with experimental investigations in this laboratory that the water content of the gelatin in high-speed photographic plates does not

FIG. 2.



show any appreciable influence on the speed in spite of the fact that the electric conductivity increases considerably as the gelatin becomes more moist.

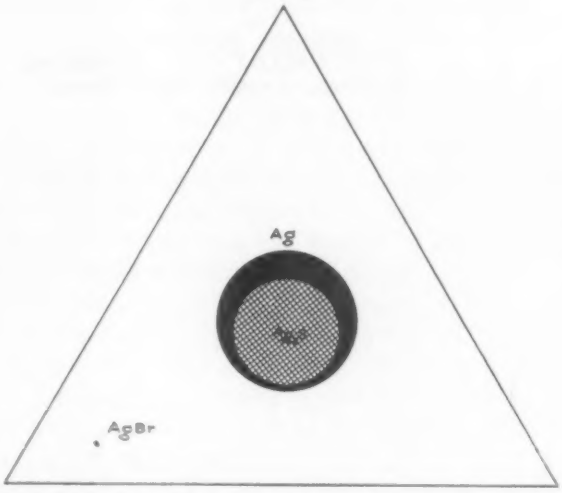
The Effect of Pre-exposure on the Results Obtained by Chromic Acid Treatment, and of Silver Sulphide as a Bromine Absorber.—Clark [13] found a difference in the resulting sensitivity when a high-speed photographic plate was treated with or without a preliminary flash exposure with a mixture of chromic acid and sulphuric acid, the former method producing a much lower sensitivity than the latter. This mixture dissolves silver rapidly, but attacks silver sulphide very slowly. The result is shown in Fig. 4. There is also a decrease in sensitivity of the same order as with preliminary flash exposure if the plate is

[13] W. Clark, *Phot. J.*, **64**, 91 (1924).

treated with such exposure with oxidizers of very high oxidation potential, which destroy silver sulphide. We have here a means of distinguishing by experimental investigation how the silver sulphide alone or the silver sulphide speck plus silver affects the photographic characteristics.

Hickman [14] has shown that silver sulphide in contact with silver bromide is more or less destroyed by light action giving

FIG. 3.



silver in its place. In his theory it is the photochemically liberated bromine which produces the effect.

Clark has given us a fairly definite proof of the existence of silver as well as of silver sulphide in the sensitizing specks in high-speed plates and both he and Hickman have dealt with important phases of the latent image formation. Neither, however, has touched upon the mechanism of the light action itself. The above proposed hypothesis of latent image formation furnishes such a mechanism without the introduction of new assumptions. It is not in conflict with the investigations of Clark and of Hickman, but is rather supplemented and to a certain extent supported by them.

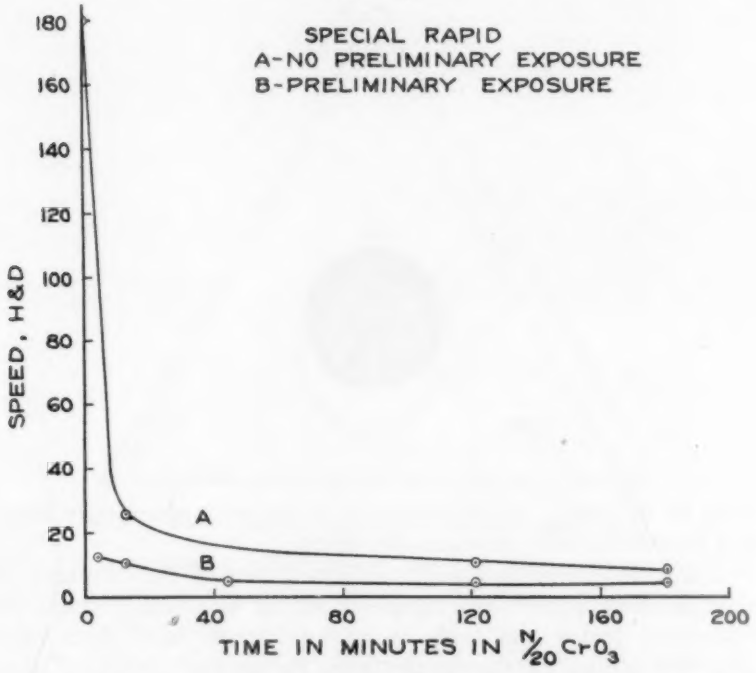
Silver Sulphide a Solid Electrolyte.—Aside from the decomposition of silver sulphide by the chemical action of bromine liberated from the silver bromide, there is another phase of the

[14] K. C. D. Hickman, *Phot. J.*, **67**, 34 (1927).

proposed mechanism, which has not yet been discussed. We know that silver sulphide is a solid electrolyte with the property of photo-conductivity, and that independently of whether or not it is photochemically light-sensitive [15] silver and sulphur should tend to be liberated as soon as an electric current passes through it.

Recently C. Tubandt and M. Haedicke [16] have made investigations concerning the electric conductivity of silver sulphide and

FIG. 4.



these are in agreement with previous work which showed that it behaves not as a metallic conductor, but as a solid electrolyte, in which only the cations move with the current. The photo-electric current going through the silver sulphide anode therefore dissociates the silver sulphide; the silver ions move towards the cathode, the sulphur ions remain where they were in what is left of the crystal lattice, only losing their electric charges.

[15] Lüppo-Cramer (*Eder's Jahrb.*, 17, 30 (1903)) was not able to determine this.

[16] *Z. anorg. Chem.*, 160, 297 (1927).

The flash exposure preliminary to chromic acid treatment, according to Hickman's and the present hypothesis, lessens the amount of silver sulphide in the speck both by the chemical action of bromine, and by the electrolytic decomposition of the silver sulphide; and the silver set free in each case, as well as that already present, is dissolved by the chromic acid. Without the flash exposure the silver sulphide portion of the speck retains practically its original size after the chromic acid treatment and hence the sensitivity is greater than in the first case.

COLOR SENSITIVITY.

Lüppo-Cramer's and Eder's [17] observations of the color sensitivity of photographic emulsions which contain adsorbed colloidal silver require consideration in connection with this hypothesis. Some high-speed photographic emulsions prepared in the ordinary way possess a slight sensitiveness to red rays, sometimes extending through the yellow into the green.[18] Renwick [19] supposes that this color sensitivity is due to colloidal silver.

A similar phenomenon is the Becquerel effect which consists in the production of a long wave-length (red, yellow) sensitivity through exposure to light of shorter wave-lengths (blue, violet, ultra-violet) and which probably is also due to (the photochemical formation of) colloidal silver on or in the silver bromide (photohalide) during the first exposure.

Another case of color sensitivity was discovered by E. R. Bullock.[20] It is believed that silver sulphide specks are formed on silver halide grains by treating a photographic emulsion with very dilute sodium thiosulphate solutions. When such treatment is given a strong sensitivity band appears in the extreme red and in the infra-red.

We have therefore a dual behavior in the sensitizing action of silver specks and of silver sulphide specks. In one case they increase, we think, blue and violet sensitivity; in another case they may behave as an optical sensitizer.

In various publications concerning the concentration speck theory the statement was made that for the formation of the latent image the silver halide is to be regarded as the light-

[17] J. M. Eder, *Phot. Korresp.*, **46**, 277, 346 (1909).
[18] Lüppo-Cramer, *Wissensch. Arbeiten*, 107.
[19] F. F. Renwick, *J. Soc. Chem. Ind.*, **39**, 156T (1920).
[20] *Cf.* S. E. Sheppard, *B. J.*, **73**, 33 (1926).

sensitive material. Color sensitivity through optical sensitizing has therefore to be explained by the color sensitivity of the system silver halide-optical sensitizer, the optical sensitizer or its combination with silver halide being an agent able to absorb wavelengths for which the pure silver halide has very little, if any, sensitivity.

The theory of the formation of the latent image here presented is not able to explain the color sensitivity produced through the action of optical sensitizers without introducing a new hypothesis. We do not know whether or not it is possible to change the photo-conductivity of silver halide in other regions of the spectrum than in those usually affected through the adsorption of a suitable dye at the surface of the silver halide grain. This has to be investigated and is within the possibility of experimental control. For the moment we have to accept it as an additional, quite plausible hypothesis.

In other words, we can tentatively regard color sensitivity as produced by centres (dye particles) which absorb the light energy in other regions of the spectrum than those in which pure silver halide absorbs. These centres become excited and transfer their absorbed energy to the silver halide, which in turn liberates the electrons, which thus produces increased conductivity.

To obtain color sensitivity it is believed that the dye speck has to lie so that a photo-electric field around the silver-silver sulphide speck can be produced by the light. By this assumption we can also explain the dual sensitizing action of silver, if we assume that it is possible that aside from the weak spots at which the silver-silver sulphide speck is formed on the surface of the silver halide grain, other weak spots where reduction may take place may be present; then if silver is formed or introduced at these spots, provided they are within the range of the circuit of the photo-electric current, they will increase sensitivity to wavelengths longer than the blue.

The same picture holds for the Becquerel effect. Instead of the reduction taking place by the action of the gelatin during ripening, the silver specks (colloidal silver) are formed by exposure. If photochemical reduction takes place at the edges of an isolated silver sulphide speck autosensitizing through the formation of a photo-electric circuit appears, and if this happens so quickly that there is no chance for the formation of isolated

colloidal silver specks elsewhere on the silver halide surface no Becquerel effect will be obtained. But if colloidal silver specks do form on a number of isolated weak spots, it is assumed that the Becquerel effect will be noticeable only if these are able to form a photo-electric field with the system $Ag|AgBr|Ag_2S$.

Similar reasoning may be applied to the color sensitivity produced by silver sulphide, *i.e.*, the phenomenon investigated by Bullock. Bullock worked with high-speed plates. The silver sulphide specks were formed in a quite different way than with allylthiourea. If these silver sulphide specks are isolated in the silver bromide and are distributed in a highly dispersed state, and if a number of them lie in the range of the electric field produced by light in the photo-electric cell, $Ag|AgBr|Ag_2S$, color sensitivity may be produced.

Some Remarks in Connection with Hickman's Theory and the Concentration Speck Theory.—It is obvious in Hickman's theory that the bromine absorption by silver sulphide can take place only at the interface between the solid electrolytes. The bromine does not move as an anion in the electric field, but can act immediately only when liberated at the interface, or more slowly by gradual diffusion to it. Even in the latter case the dimensions of the photo-electric cell are so minute that diffusion of the liberated bromine molecules towards the silver sulphide speck should not require very long. In accepting the photo-conduction theory of the latent image formation, therefore, one should not disregard Hickman's theory. The concentration speck theory did not distinguish sharply between the developability produced by the silver sulphide speck and by the silver speck in the silver bromide grain. Hickman drew a distinction between these, stating that the silver speck probably is more effective in causing developability than the silver sulphide speck. In the writer's opinion this is an important point which should be investigated experimentally.[21]

ACKNOWLEDGMENT.

My thanks are due to Dr. C. E. K. Mees, Dr. S. E. Sheppard, Mr. L. A. Jones, Dr. L. Silberstein, Dr. E. P. Wightman and Dr. K. C. D. Hickman for their criticisms and valuable contributions to the development of this hypothesis, and especially to

[21] For further discussion of this subject see E. R. Bullock, "Chemistry of the Latent Image," Monograph, Chapter VI, to be published soon.

Dr. E. P. Wightman, in addition, for helping me in the writing of this and the preceding paper.

SUMMARY.

(1) Based on the theoretical conclusions of Wightman and Quirk in their investigations on the action of hydrogen peroxide on high-speed plates, and of Clark's experiments on the action of oxidizers on sensitivity and latent image, which indicate that the sensitizing speck of high-speed photographic emulsions, as well as the latent image, probably consists of both silver and silver sulphide, a probable elementary photo-electric cell on the surface of the silver halide grains can be pictured.

(2) A proposed mechanism of the action of this cell in producing sensitivity is described.

(3) Assuming that optical sensitizing is due to an increase of the photo-conductivity for longer wave-lengths, a possible mechanism is given of how either certain dyes, or silver, or silver sulphide could act as an optical sensitizer to increase the sensitivity of silver halide for wave-lengths longer than the blue. This mechanism is based upon the assumption that dye specks, or finely divided silver, or silver sulphide, lying in the field of the photo-electric cell, $Ag|AgBr|Ag_2S$, increases its photo-conductivity above that of such a cell without one of these substances present, to wave-lengths longer than the blue. The range and intensity of the color sensitivity is dependent not only upon the absorption of light of given wave-lengths, but also upon the size and distribution of the specks of impurity.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

COÖPERATIVE WORK WITH FOREIGN LABORATORIES IN METHODS OF DETERMINING GASES IN METALS.

For several years the bureau has been interested in the development of methods for determining gases in metals, particularly in iron and steel. Recent work along this line has been the development of vacuum fusion methods of analysis and the comparison of these with earlier methods.

While the rôle which may be played by the amounts of gases normally present in commercial irons and steels is not yet clearly defined, nevertheless it is quite general belief of interested chemists and metallurgists that the gas content of iron and steel deserves some very careful study. The metallurgical laboratories of a number of American manufacturers have lately undertaken analyses for gases in metals. Similar methods of analysis are employed to some extent in England, Germany and Sweden.

In order that the data on the gas content of metals, which presumably will be gathered by these various widely separated laboratories, might have some basis of intercomparison, it seemed very desirable that analyses should be made on samples of the same irons and steels by a number of these laboratories. This was all the more necessary because some of the methods of analysis in general use are comparatively new and their limitations may not as yet be fully recognized. The bureau distributed samples of an ingot iron for gas analyses to Prof. C. H. Desch, of the University of Sheffield, Sheffield, England, to the late Prof. P. Oberhoffer, of the Institut für Eisenhüttenkunde, Aachen, Germany, and to a coöperating laboratory in Sweden. The results from the English and German laboratories have just been reported. The analyses at Aachen were carried out by Doctor Hessenbruch after the death of Professor Oberhoffer. No results are as yet available from the Swedish laboratory.

* Communicated by the Director.

The composition of the ingot iron distributed was as follows:

	Per Cent.
Carbon	0.04
Manganese	.03
Sulphur	.02
Silicon	.006

The analyses at Sheffield were made by the hydrogen reduction method, using a solid sample with the addition of an antimony-tin alloy. The analyses at Aachen were made by a vacuum fusion method, heating by high-frequency induction in a graphite crucible essentially as in the Bureau of Standards method described in *Scientific Paper No. 514*. The German method, however, differs from the bureau's method in that the evolved gases are collected and determined volumetrically. The analyses at this bureau were carried out by the vacuum fusion method as regularly employed and as described in the above-mentioned scientific paper. The results obtained by the coöperating laboratories are as follows:

Laboratory.				
University of Sheffield.	Institut für Eisenhüttenkunde.		Bureau of Standards.	
Type of Analytical Method.				
Hydrogen Reduction (with Antimony-tin Addition).	Vacuum Fusion (Volumetric).		Vacuum Fusion (Gravimetric).	
Oxygen.	Oxygen.	Hydrogen.	Oxygen.	Hydrogen.
Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
0.056	0.055	0.0008	0.057	0.0005
.057	.059	.0008	.059	.0005
.049	.062	.0007	.058	.0007
.048	.....	.....	.058	.0008
.049	.....	.....	.....	.....
.051	.....	.....	.....	.....
Av..... .051	.059	.0008	.058	.0006

For this particular class of material, an ingot iron, the two modifications of the vacuum fusion method give practically the same values for oxygen. The hydrogen-antimony-tin reduction method, using a solid sample, gave a value for oxygen but slightly lower. The average value for hydrogen was slightly

higher by the volumetric vacuum fusion method than by the gravimetric vacuum fusion method.

Similar coöperative analyses of steels and cast irons seem desirable and steps have already been taken to initiate further coöperative work.

PREPARATION AND ELECTRICAL PROPERTIES OF RUBBER HYDROCARBON.

IN CONTINUATION of an investigation on the electrical properties of rubber,[1] a new method is being developed for the production of rubber hydrocarbon.

Crude or natural gum rubber contains about 93 or 94 per cent. of the hydrocarbon to which it owes its characteristic properties; the remainder of the composition is made up of proteins and resins, each to the extent of 3 or 4 per cent., while inorganic salts and other constituents amount to a fraction of 1 per cent. Essentially the method of obtaining the hydrocarbon consists in the removal of the non-hydrocarbon constituents from raw rubber in such a way as to leave the hydrocarbon itself in its original state, as nearly as this may be possible.

Removal of the protein is accomplished by digesting crude rubber with water, or with a water-alcohol mixture, at an elevated temperature. In some experiments the digestion was carried out for ten hours at 185° C. Subsequent extraction with acetone removes the resins and also any residual protein hydrolysis products. A portion, though not all, of the salts are removed by the treatments with water and acetone. After the acetone extraction, the product is dried to constant weight.

In appearance and consistency rubber hydrocarbon prepared by this process does not differ greatly from well-milled crude rubber. There is no indication of any marked change in the nature of the hydrocarbon from its state in the original crude rubber.

Complete analysis of the rubber hydrocarbon has not yet been made. The fact that the material is colored is evidence of the presence of impurities, though perhaps in small amount. The nitrogen content of one lot of hydrocarbon was 0.02 per cent.,

[1] "Density and Electrical Properties of Rubber-Sulphur Compounds," H. L. Curtis, A. T. McPherson, and A. H. Scott. *Scientific Papers of the Bureau of Standards No. 560*, 1927.

the portion insoluble in benzene was 0.17 per cent., and the ash, 0.08 per cent. The purity of the hydrocarbon is probably of the order of 99½ per cent. For present purposes, high purity is considered less essential than the preservation of the original molecular state of aggregation of the hydrocarbon.

Rubber hydrocarbon undergoes vulcanization on heating with sulphur. Electrical test specimens have been made of compounds of rubber hydrocarbon with sulphur covering the entire range of composition from the hydrocarbon alone to hard rubber. Measurements of dielectric constant, power factor, and resistivity on two lots of hydrocarbon, one derived from pale crepe and the other from up-river Para rubber, gave practically identical results.

The electrical properties of rubber hydrocarbon and its compounds with sulphur differ quite materially from the properties of raw rubber and its sulphur compounds. Specific data on the electrical properties are not available for publication at this time.

NEW EQUIPMENT IN LENGTH SECTION.

THE installation of equipment in the new underground comparator and dividing engine room of the length measurement section has been completed. Active testing work in the new laboratory was started late in November. The calibration of a one-metre bar submitted several months ago has been nearly completed, and observations made for a calibration of the bureau's laboratory meters. Definite arrangements have been completed for a program of line standard calibration which is very necessary. The work will be started at once. Another line of work involving circle graduation and calibration will also be commenced.

FUNDAMENTAL STUDY OF GLAZE FIT.

AN INVESTIGATION is being conducted at the Columbus branch of the bureau to determine the effect of the various oxides on the tensile strength, modulus of elasticity and coefficient of expansion of glazes. Factors applicable to the various oxides have been worked out for the modulus of elasticity and tensile strength of the glazes based on the batch compositions.

The Fizean-Pulfrich method, which has been in use for a number of years at the bureau for the measurement of small dilatations, was used in determining the coefficient of linear

expansion of the glazes. The extreme sensitiveness of the interferometer makes it possible to work with a small specimen of the material. The rods used in this work varied from 0.3 to 0.8 mm. in thickness. The small size of this apparatus simplifies the problems of uniform heating and temperature control. The heating rate used in this work was 3° C. per minute.

The coefficient of expansion has been determined on about 75 per cent. of the glazes (95 have been melted and fired). It has been found necessary to heat the glazes to a critical temperature before determining the expansion behavior. This is necessary before a reproducible expansion curve can be obtained for the glazes. All of the rods were annealed before the physical properties were determined. The annealing temperature for the experimental glazes was found to vary from 315 to 725° C. depending upon the composition.

The temperature expansion curves obtained for the glazes are not strictly linear, as the slope increases slightly with the temperature. The mean coefficient of linear expansion has been calculated and is found to vary from $.0456 \times 10^{-4}$ to $.1581 \times 10^{-4}$. The former value is for a high magnesium glass, while the latter is for a high soda-potash glass.

The values for the oxides seem to be arranged in about the following order: Na_2O, K_2O, BaO, PbO, B_2O_3, ZnO, CaO, Fe_2O_3, Al_2O_3, MgO, SiO_2. This arrangement is only tentative and probably will be found to vary in the different types of glazes. Thus the value for B_2O_3 passes through a minimum at about 20 per cent. in lead glazes.

The chemical analysis of the glazes is about 40 per cent. completed at present. It was found necessary to analyze the material rather than use the batch composition because of volatilization of constituents and reaction with the pots.

CRACKING OF PAINT FILMS.

THE paint section of the bureau has constructed apparatus for determining when a paint, varnish, or bituminous coating on a metal panel has failed by cracking. Such failures cannot ordinarily be seen with the naked eye unless the cracks are very bad.

The operation of the apparatus follows: (1) A metal panel is coated on one side with the paint. (2) A set of headphones is connected in series with the back of the panel. (3) The

painted surface is stamped with a number of drops (50 in all) of a conducting solution prepared so as to wet the surface. (4) A voltage from an interrupted source is placed across the headphones and panel, and the circuit completed by touching the return wire to the drops. If there is a break in the paint film a loud buzz will be heard in the headphones.

So far the results obtained by this method check with observations made on the paint.

INCREASING THE DURABILITY OF UNITED STATES PAPER CURRENCY.

THE investigation which the Bureau of Standards has been conducting in coöperation with the Bureau of Efficiency and the Bureau of Engraving and Printing with the object of increasing the life of United States paper currency was briefly described in *Technical News Bulletin No. 109*, May, 1926. This work is being actively continued.

One of the most important facts discovered during the past year was that the strength imparted to currency paper by glue sizing is practically all destroyed in the processes used to print the paper. On the other hand, it was found that the basic strength of the paper, that is, the strength produced by the paper fibres, is not impaired by the printing. This has led the Treasury Department to adopt the type of paper developed by the Bureau of Standards as the standard currency paper, because the distinctive feature of this paper is its high fibre strength. Another desirable characteristic of the paper is its lack of grain. It has a folding strength in the two principle directions of over 5000 double folds. A study of commercial papers showed that the Bureau of Standards' paper had no counterpart commercially. In view of this situation fine-paper manufacturers in general were asked to coöperate in commercial development of the new type of paper. Several concerns conducted paper-making experiments in their mills, following the bureau's paper-making procedure. Commercial papers were produced equal in strength and printing quality to those produced in a semi-commercial way in the Bureau of Standards' mill. This showed that the paper-making procedure developed by the bureau is entirely feasible commercially, and therefore that the Treasury Department will not experience difficulty in obtaining the desired type of paper.

Additional problems in the paper manufacturing processes are being studied in the bureau's mill. Results so far obtained in investigation of the relative merits of cotton and linen fibres indicate that a part of the expensive linen fibres can be replaced by the cheaper cotton fibres without material injury to the quality of the paper. Also it is believed that caustic soda is preferable to lime in cooking the paper-making rags, in respect to both strength of the paper and its printing quality. Additional glue surface-sizing data obtained indicate that formaldehyde is preferable in many respects as a preservative for the paper glue-sizing solution, to the more commonly used alum.

It is estimated that these investigations have resulted so far in increasing the life of the paper currency over 40 per cent. It is believed that this figure will be further increased as additional improvements are put into effect.

The Luminescence of Solid Nitrogen under Cathode-ray Bombardment. J. C. McLENNAN, H. J. C. IRETON and K. THOMSON. (*Proc. Roy. Soc.*, A773.)—The significance of this paper lies in its relation to the origin of the famous green line in the spectrum of the aurora and of sky-light at night. The Norwegian physicist, Vegard, proposed a theory that required this line to be emitted by solid nitrogen in the upper air. At Leyden he bombarded solid nitrogen with cathode rays and saw that it became brilliantly luminescent. He distinguished four bands in the spectrum of the light thus obtained. One of them in the yellow-green covered a region of the spectrum that included the green line. He drew the conclusion that this line by his experiment as well as by his theory was due to solid nitrogen. In Toronto, McClennan and Shrum, having likewise subjected solid nitrogen to bombardment, failed to agree with Vegard on the origin of the green line. They were led to their conclusion by a study of the structure of Vegard's band and by their having got from an electrical discharge in pure oxygen a line with exactly the same wave-length as the green line. Their results have been confirmed by other physicists.

In one form of apparatus employed in the experiments described in this paper, nitrogen solidified on the walls of a bulb forming part of the tube in which the electrical discharge passed. Liquid hydrogen was maintained outside of the tube. The discharge from the cathode was directed upon the solid nitrogen. During the passage of the discharge a wide yellow-green band was emitted by the nitrogen, the luminescent band. After the cessation of the discharge "an intense phosphorescence of the solid nitrogen was observable. Fine print could be read at a distance of 6 inches from the glowing bulb. The luminescent and phosphorescent bands appeared to come only from the form of solid nitrogen that existed below a certain temperature. When the hydrogen was allowed to evaporate the nitrogen warmed up slowly, and at a certain temperature a marked change in the appearance of the solid nitrogen occurred. Below this critical temperature it had an appearance like that of ice, but when the critical temperature was reached it suddenly changed to a powdery white form that fell off the upper parts of the bulb. This powdery form exhibited none of the luminescent effects which the ice-like form showed. The temperature at which this transformation takes place has been found by other observers to be 35.5° K."

The structure of the nitrogen bands is shown in reproductions of photographs of the spectrum. It is even possible to furnish data on the moment of inertia of the molecular system emitting the bands. Certain bands found by Vegard, however, could not be obtained even with long exposure. G. F. S.

NOTES FROM LIGHTING RESEARCH LABORATORY, NATIONAL LAMP WORKS OF GENERAL ELECTRIC COMPANY.*

HETEROCHROMATIC PHOTOMETRY.[1]

By A. H. Taylor.

TWELVE years ago Dr. H. E. Ives proposed a method for use in selecting observers for heterochromatic photometry when the flicker photometer is used. The procedure consisted of having each observer determine the relative transmission-factor of yellow and blue solutions when used to filter the light from carbon lamps operating at a definite efficiency. The concentrations of the solutions were so adjusted that an observer of average color vision obtained equal transmission-factors for the two solutions.

A recent investigation has been carried out in this laboratory to determine the accuracy of results obtained by a flicker photometer with a 3° flickering field surrounded by a uniformly bright field of constant intensity. Nine observers were used, each observer being tested first with the Ives' solutions. Thirteen filters, about half of which were fairly saturated colors, were measured with the flicker photometer. The results for the various observers were then plotted to show the relation between the

Filter.	Color.	Flicker Photometer. (Per Cent.)	Integral Transmission-Factor Computed from Spectral Data. (Per Cent.)
DR–1	Dark red	11.92	12.54
R–4	Dark red	7.90	8.40
MR–7	Medium red	17.80	18.81
R–2	Medium red	26.4	26.9
OA–1	Orange-amber	38.4	38.2
A–1	Amber	46.4	46.9
BS–71	Light yellow	71.3	71.3
LA–1	Light yellow	73.8	73.7
B–1	Light blue	45.8	46.3
LB–1	Medium blue	11.42	11.39
DG–1	Dark green	9.02	8.94
B–5	Dark blue	2.18	2.17
DB–1	Dark purplish-blue	0.230	0.165

* Communicated by the Director.

[1] To be published in full in the *Trans. Illum. Eng. Soc.*

color sensitivity of the observer (as determined by the yellow and blue solutions) and the transmission-factor found for each filter. From the plots thus obtained the value for an "average" observer, as defined above, was scaled off, and this was the integral transmission-factor assigned to each filter. Later the spectral transmission of each filter throughout the visible spectrum was measured, and the integral transmission-factor of each was computed by the use of normal visibility data which have been internationally adopted. The table compares the results obtained in these two ways.

THE ABILITY OF THE EYE TO COMPENSATE FOR POOR VISUAL CONDITIONS.

By P. W. Cobb and F. K. Moss.

IF A visual task is done under two conditions, one favoring vision and the other making vision difficult, the result sometimes shows that the speed and accuracy of the work are about the same. The difficulties in vision have thus been offset by increased effort on the part of the worker, very much as one "steps on the gas" in driving a machine uphill. For this reason experimentation often will not show the differences in the "ease of vision" which are probably present. Two experiments will be cited as examples:

(*a*) The subject read a quantity of printed matter—first, with the reading matter held by a stationary rack and, second, with the rack vibrating. The subject expressed no doubt that the vibrating condition was the more difficult, still the measurement of the two rates of reading showed no difference.

(*b*) A test was devised which required the subject to perform a triple task, including exacting visual work. The speed and accuracy of his work were measured. The test was applied under two different conditions: First, when the subject was in a rested condition and again after thirty minutes of exacting work with the eyes. The difference between the two test-results was slight, and indicated that the subject was capable of working slightly faster and more accurately after the thirty minutes of fatiguing work than before. The test was also repeated, using the normal work of the day instead of the thirty-minute period of extremely

difficult work, one measurement being made at the beginning and the other at the close of the work-day, and similar results were obtained.

These experiments show the difficulty encountered in using the efficiency of work as a measure of visual fatigue. The effect to be determined is often obscured, principally by reason of the readiness with which the visual organs adapt themselves to widely different conditions even at the expense of greater strain and fatigue.

The Magneto-optical Effect and a Correction. ELIHU THOMSON. (*Nature*, Oct. 22, 1927.)—In 1921 Elihu Thomson called attention to the phenomenon, which he summarizes thus, "A magnetic field produced by a direct current, permanent magnet, or by interruptions or alternations of current, is rendered visible even when very weak, by a light smoke from an iron arc; such fume or smoke being effective for the purpose even when so thin or diffused as to be scarcely noticeable in the air. Such smoke, diffused in the space where a field exists, when illuminated from above by sunlight or an artificial source and viewed in a direction across the light beam and more or less normal to the direction of the lines of force of the field, apparently becomes luminous, but in reality becomes a far better reflector diffuser in certain directions of the incident light than when the field lines are absent. Viewed along the magnetic lines, no increased luminosity is produced even when the field is strong or the illumination strong, or both.

"The conditions for its observations seem to be: (1) Illumination transverse (more or less) to the direction of the lines of the field. (2) Viewing in a direction more or less transverse to the lines of the field and to the direction of the incident light."

The contrast between what is seen with the magnetic field and without it is made much more distinct by using denser iron smoke. This consists of ferric oxide. "The illumination from the smoke particles was found to be polarized as if produced by reflection from strings of fine particles, oriented in the direction of the field lines."

The author emphasizes the very small amount of smoke required for the detection of the effect and the promptness of the response to weak fields. If some smoke be caught in a glass flask this, when illuminated, shows flickering even at a distance of twelve feet from a coil traversed by a low-frequency current. When the flask is close to the coil there is no flickering but a steady illumination. By the use of the smoke the rotating fields produced by biphase, three-phase and polyphase currents have been made visible to the eye and subject to photographic registration. The illuminated iron smoke in a rotating field displays a rotating glow. The author suggests several possible practical applications of the effect he describes. He corrects a former statement that with an alternating-current field the flickering keeps step with the cycles. In fact, it is with the alternations that the flickering keeps time. The error was due to misinformation as to the number of cycles in an experiment. G. F. S.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

THE FOG CORRECTION OF PHOTOGRAPHIC DENSITIES.[1]

A SENSITOMETRIC STUDY.

By H. A. Pritchard.

THE Wilsey fog correction, based on the assumption that the mass of silver developing as fog is proportional to the mass of silver unaffected by exposure, omits several factors which, unless the fog is small, have an appreciable effect. In the present work, experimental fog correction functions were obtained by a study of the growth of fog at long development times after image density has practically been completely developed. These gave more consistent sets of corrected sensitometric data than previous methods of fog correction.

If image density was practically completely developed before fog reached a value of 0.5, the Wilsey method of fog correction appeared to give satisfactory results.

The Bloch method of measuring fog in a small protected area in the centre of each density indicated that the influence of reaction products on development was practically negligible with the developer used (Elon-hydroquinone X-ray formula).

By prolonged development, it was found possible to develop all the silver in the film as fog. The maximum fog density, however, was considerably less than maximum image density.

In the lower exposures, the reversal effect observed on positive film at long development times was found to remain at complete development of all the silver in the film.

The large variations in photometric equivalent are believed under extreme conditions to contribute considerably to the failure of the Wilsey fog correction.

* Communicated by the Director.

[1] Communication No. 310 from the Kodak Research Laboratories and published in *Phot. J.*, **67**, 447. 1927.

THE LOWER FATTY ACIDS OF COCONUT OIL.[2]

By E. R. Taylor and H. T. Clarke.

A SYSTEMATIC fractionation of about 130 kg. of methyl esters of coconut oil acids has been carried out. The lower fatty acids have been found in the following percentages:

	Per Cent.
Methyl caproate	0.47
Methyl caprylate	8.0
Methyl caprate	5.7
Methyl laurate	45.2
Methyl myristate	16.5
Higher esters	23.4

These results give definite information as to the quantitative distribution of the various lower acids in the original oil. The following acids have been isolated from the esters: Caproic acid, caprylic acid, capric acid, lauric acid, and myristic acid.

AUTOMATIC SILVER RECOVERY FROM HYPO.[3]

By K. C. D. Hickman and D. E. Hyndman.

OF THE many methods of treatment adequately described by Crabtree and Ross, those using zinc dust or sodium sulphide are the most popular. The hypo solution is permitted to accumulate until the tank is full, reagents are added, and the desilvered hypo allowed to flow to waste after settling over night.

The scheme described in the present paper uses the conventional sodium sulphide method but performs the operation continuously and automatically. Waste hypo is allowed to drop into a measuring vessel fitted with an automatic syphon which flushes at a predetermined head. During the flushing operation waste developer and sodium sulphide are sucked in and the mixture discharged into a reaction vessel. From here the solution and precipitate trickle slowly down a funnel to a settling tank. The precipitate collects as a thick brown sludge below the funnel and is drawn off into a bucket with a perforated bottom covered with absorbent cotton. The clear, desilvered hypo flows to waste from the top.

[2] Communication No. 311 from the Kodak Research Laboratories and published in *J. Amer. Chem. Soc.*, **49**, 2829, 1927.

[3] Communication No. 328 from the Kodak Research Laboratories and published in *Brit. J. Phot.*, **74**, 683, 1927.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

PROTEINS OF SESAME SEED, SESAMUM INDICUM.[1]

By D. Breese Jones and C. E. F. Gersdorff.

[ABSTRACT.]

By extracting the oil-free meal of sesame seed with 10 per cent. sodium chloride solution, two globulins differing in precipitability with ammonium sulphate, in solubility, elementary composition, and distribution of nitrogen were obtained. The α-globulin was obtained as crystals in the form of tetragonal bipyramids. The β-globulin consisted of an amorphous, white powder. The meal contained approximately four times as much α-globulin as β-globulin.

By heating sodium chloride extracts of the sesame meal to 68° C. a coagulum (Fraction 1) containing over 42 per cent. of ash was obtained. The mineral constituents of ash consisted almost entirely of magnesium, phosphorus, sodium, and potassium. This coagulum contained 12 per cent. of nitrogen as calculated on an ash- and moisture-free basis. It responded positively to the usual tests for proteins.

The distribution of nitrogen in both the globulins and Fraction 1 was determined by the Van Slyke method; cystine, tyrosine, and tryptophane were determined colorimetrically.

THE IODIMETRIC EVALUATION OF METHYLENE BLUE.[2]

By Walter C. Holmes.

[ABSTRACT.]

IN THE precipitation of methylene blue by iodine solutions the presence of acid restricts the absorption of iodine by the dye, and the proportion of iodine taken up is dependent, primarily, upon the concentration of residual iodine in the solution.

For accurate work the official method must be calibrated for variation in dye concentration.

* Communicated by the Chief of the Bureau.

[1] Published in *J. Biol. Chem.*, **75**, 213–225, Oct., 1927.

[2] Published in *J. A. O. A. C.*, **10**, 505–507, Nov., 1927.

THE SPECTROPHOTOMETRIC DETECTION OF BORON.[1]

By Walter C. Holmes.

[ABSTRACT.]

MINUTE quantities of boron in solution are detected by the use of the spectrophotometer. The approximate boron content in the solutions tested ranged between one part in six million and one part in eighteen million. It is concluded that if duplicate or triplicate determinations are made with care, the test is adequate for the detection of one part of boron in twenty-five million parts of aqueous solution.

[1] Published in *J. A. O. A. C.*, 10, 522–523, Nov., 1927.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting Held Wednesday, December 21, 1927.)

THE stated monthly meeting of the Institute was called to order by the Vice-president, Walton Forstall, Esq., at eight-fifteen P.M. The Secretary announced that the minutes of the November meeting had been printed in full in the December number of the JOURNAL of the Institute, and therefore moved that they be approved as printed. The motion was seconded and unanimously adopted.

The Secretary announced that since the last meeting, eight new members had been added to the Institute, and two former members had been reinstated. He announced with sincere regret the death of five members and stated that proper citation of these deaths had been made in the JOURNAL.

The Secretary made a statement concerning the Christmas Week Lectures to be given by Prof. Wilder D. Bancroft, and urged members and friends of the Institute to attend the lectures, but especially to induce young people to attend.

This being the meeting at which nominations of officers and members of the Board of Managers for the ensuing year must be made, the Secretary presented the following nominations which had been offered by various members:

Office.	Nominee.	Term.	Nominated by:
President	Dr. Wm. C. L. Eglin	1 year	Dr. Walton Clark Mr. Walton Forstall
Vice-president	Mr. Henry Howson	3 years	Dr. W. F. G. Swann Dr. James Barnes
Treasurer	Mr. Benjamin Franklin	1 year	Mr. W. H. Bristol Dr. G. A. Hoadley
Board of Managers:	Mr. Francis T. Chambers Mr. Morris L. Clothier Mr. Nathan Hayward Mr. Robert W. Lesley Mr. Marshall S. Morgan Mr. E. H. Sanborn Mr. S. T. Wagner Mr. J. T. Wallis	3 years	Mr. Haseltine Smith Mr. W. G. Littleton Mr. Frank H. Stewart

The Chairman called for any additional nominations from the floor, and as none was offered, he declared the nominations closed, and stated that ballots would be submitted in advance of the January meeting, at which the elections will be held.

The Secretary called to the attention of the meeting the fact that notice had been given to the Board of Managers in June of proposed amendments to

the By-Laws, having to do with the management of the Bartol Research Foundation. The requirement of the By-Laws of at least sixty days' notice having been complied with, he presented the following suggested amendments, with the approval of the Board of Managers and the Bartol Research Foundation Committee:

PROPOSED AMENDMENT TO THE BY-LAWS OF THE FRANKLIN INSTITUTE.

ARTICLE V. *Duties of Officers.*

SECTION 3. Substitute for the last sentence the following:

"He shall be ex-officio a member of the Board of Managers and of all standing committees of the Institute, and of the committees on Membership, Publications, and the Bartol Research Foundation of the Board of Managers. He may be appointed to membership in any of the other committees of the Board of Managers."

ARTICLE VII. *Committees of the Board of Managers.*

For the fifth paragraph, dealing with the Bartol Research Foundation Committee, substitute the following:

"The Bartol Research Foundation Committee shall have full charge of the activities of the Bartol Research Foundation. It shall appoint the Director of the Laboratories, the professional staff, and all persons engaged in research, subject to the approval of the Board of Managers of the Institute. It shall be composed of thirteen members: The President of the Institute, the Secretary of the Institute, and the Director of the Bartol Research Laboratories, who shall be ex-officio members of this Committee; four members of the Board of Managers appointed by the President, with the approval of the Board; and five members of the Institute not members of the Board of Managers, appointed by the President, with the approval of the Board.

"Advisory committees for any purpose may be appointed by the President of the Institute, upon recommendation of the Bartol Research Foundation Committee.

"All questions of policy shall be in the control of the Bartol Research Foundation Committee, subject to the approval of the Board of Managers of the Institute. The details of the scientific activities of the Foundation shall be in the hands of the Director, who shall, however, report upon all matters to the Committee, as desired.

"The Director of the Bartol Research Laboratories shall report to the Bartol Research Foundation Committee. All other employees of the Foundation shall report to the Director. The Committee shall have full power to carry out the purposes of the Foundation, subject to the approval of the Board of Managers. After each of its regular meetings, a report of its operations shall be made to the Board of Managers."

The Secretary moved that these amendments be approved. This motion was duly seconded and unanimously adopted.

There being no further business, the Chairman of the evening very felici-

tously presented the speaker of the evening, William H. Bristol, Esq., of Waterbury, Conn., who spoke on "Talking and Synchronized Motion Pictures," before an audience which completely filled the lecture room.

Mr. Bristol presented by means of lantern slides, mechanical models, and actually operating machines, the method of producing talking moving pictures which he had devised. He showed how synchronization could be produced, and then how by his method synchronization which had been lost could be restored without any interruption to the display of the film or of the sound.

A recess was taken at nine-forty-five P.M. to enable those to leave who had to catch trains. Only a few left. The meeting continued until eleven-twenty, when it was adjourned by the Secretary, out of consideration for the weariness of Mr. Bristol and his operators.

The whole demonstration was singularly effective and the meeting was pronounced enthusiastically a great success.

A rising vote of thanks was taken at nine-forty-five, whereupon the audience resumed their seats. The meeting finally adjourned at eleven-twenty.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting Held Wednesday, December 7, 1927.)

HALL OF THE COMMITTEE,
PHILADELPHIA, December 7, 1927.

MR. M. M. PRICE *in the Chair.*

The following report was presented for final action:

No. 2876: Permalloy.

The specific purpose of the invention of permalloy is to produce a magnetic material having high permeability and low hysteresis loss for the low range of magnetizing forces used in the communication field.

The initial permeability of permalloy and its permeability through the range of magnetizing forces up to .2 of a c.g.s. unit are greater than thirty times that of the best soft iron.

Permalloy is produced by combining pure iron and nickel, the highest initial permeability being found when the metals are in the proportion of 21.5 per cent. of iron and 78.5 per cent. of nickel.

The Elliott Cresson Medal was recommended to Mr. Gustaf W. Elmen, of the Bell Telephone Laboratories, New York, "in consideration of his extended researches in the magnetic characteristics of nickel-iron alloys resulting in the invention of permalloy, an alloy having high permeability and low hysteresis loss, and of its successful uses for the loading of submarine telegraph cables

to secure high-speed transmission, for the cores of loading coils and audio-frequency transformers."

The following reports were presented for first reading:

No. 2872: Pendulum Hardness Tester.
No. 2878: Work of Henry Ford.
No. 2886 and No. 2887 } Franklin Medal.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, December 14, 1927.)

RESIDENT.

DR. THEODORE K. CLEVELAND, Research Chemist, in care of U. G. I. Contracting Company, 319 Arch Street. For mailing: 115 North Fifty-second Street, Philadelphia, Penna.

MR. JOSEPH E. GIBBONS, Petroleum Technologist, Atlantic Refining Company, 3144 Passyunk Avenue. For mailing: 2311 North Seventeenth Street, Philadelphia, Penna.

MR. HARRY A. GOULD, Electrical Engineer, Philadelphia Electric Company, 1320 Wagner Avenue, Logan, Philadelphia, Penna.

MR. FRED B. KAUFMAN, Building Construction, 925 North Nineteenth Street, Philadelphia, Penna.

DR. PAUL B. TAYLOR, Physicist, Victor Talking Machine Company, Camden, N. J. For mailing: 4520 Kingsessing Avenue, Philadelphia, Penna.

DR. ALBERT H. WILSON, Associate Professor of Mathematics, Haverford College, Haverford, Penna.

NON-RESIDENT.

MR. IRVING H. CROWNE, Research Engineer, Brooklyn Edison Company, Brooklyn, N. Y. For mailing: 194 Columbia Heights, Brooklyn, N. Y.

STUDENT.

MR. JOSEPH M. LIVEZEY, Student, Mullica Hill, N. J.

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MR. JOSEPH WINLOCK, 332 West Springfield Avenue, Chestnut Hill, Philadelphia, Penna.

TRANSFERS.

FROM NON-RESIDENT TO RESIDENT.

MR. CHARLES N. FORREST.

CHANGES OF ADDRESS.

DR. DONALD S. ASHBROOK, in care of Joseph Bancroft and Sons Company, Wilmington, Dela.
DR. CHARLES E. CASPARI, 4588 Parkview Place, St. Louis, Mo.
DR. E. H. GRAFTON, in care of Murray Rubber Company, Trenton, N. J.
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MR. JAMES H. WYATT, 225 First Avenue, Haddon Heights, N. J.

NECROLOGY.

Mrs. C. C. Febiger, Philadelphia, Penna.
Mr. Henry V. Wille, Philadelphia, Penna.
Mr. R. G. Porter, Philadelphia, Penna.
Mr. G. W. Elkins, Philadelphia, Penna.
Mr. Alonzo G. Kinyon, Fullerton, Penna.

LIBRARY NOTES.

RECENT ADDITIONS.

American Medical Association.—New and Non-official Remedies. 1927.
American Medical Association.—Useful Drugs. Edited by R. A. Hatcher and Cary Eggleston. Seventh edition. 1926.
American Society for Testing Materials.—A.S.T.M. Standards. Two volumes. 1927.
BARRITT, J. W.—The Care and Operation of Machine Tools. 1927.
BONE, WM. A., and DONALD T. A. TOWNEND.—Flame and Combustion in Gases. 1927.
BORN, MAX.—Problems of Atomic Dynamics. 1926.
BOUTHILLON, LÉON, and M. GOUDONNET.—Les Lois Fondamentales de l'Électricité. Tomes 1 and 2. 1926–1927.
Brassey's Naval and Shipping Annual. 1928. Thirty-ninth year. 1927.

Chemisches Zentralblatt.—Generalregister vi, über die Jahrgänge, 1922–1924. Teil II Sachregister, Formelregister und Patentnummernregister. 1927.

DICKINSON, R. E.—Electric Trains. 1927.

HAM, C. W., and E. J. CRANE.—Mechanics of Machinery. 1927.

HEVESY, GEORGE, and FRITZ PANETH.—A Manual of Radioactivity. Translated by R. W. Lawson. 1926.

HUMPHREYS, W. J.—Fogs and Clouds. 1926.

INCE, E. L.—Ordinary Differential Equations. 1927.

KIMBALL, DEXTER S.—Principles of Industrial Organization. Third edition. 1925.

LAURY, N. A.—Hydrochloric Acid and Sodium Sulphate. 1927.

LEWIS, E. I., and GEORGE KING.—The Making of a Chemical. No date.

LONG, S. H.—Navigational Wireless. 1927.

MICHELSON, A. A.—Studies in Optics. 1927.

National Electric Light Association.—Overhead Systems Reference Book. 1927.

REINHOLT, OSCAR H.—Oildom: Its Treasures and Tragedies. 1924–1927.

RICHARDSON, E. G.—Sound: A Physical Text-book. 1927.

Soil Science. Four volumes. 1916–1917.

STEWART, A. W.—Recent Advances in Organic Chemistry. Fifth edition. Two volumes. 1927.

Swope's Lessons in Practical Electricity. Seventeenth edition by Erich Hausmann. 1927.

THORPE, SIR EDWARD.—A Dictionary of Applied Chemistry. Volume VII, with an index to the whole work. 1927.

UNWIN, W. CAWTHORNE, and A. L. MELLANBY.—Elements of Machine Design. Part I. New and revised edition. 1927.

WOOD, WM. P., and JAMES M. CORK.—Pyrometry. 1927.

BOOK REVIEWS.

THE MAKING OF A CHEMICAL, a guide to works-practice. By E. I. Lewis, M.A., B.Sc., and George King, M.Sc., F.I.C. 288 pages, 8vo. New York, John Wiley and Sons, Inc. Price, $4.

Chemical engineering as a branch of special instruction in chemistry is of comparatively recent development but its importance has grown enormously within the last few years. It is somewhat sad to say that much of this importance has arisen from the application of chemistry to war. It is true that warlike measures even at a very early period involved the employment of chemicals, for long before the invention of gunpowder various materials for destroying structures by fire or corrosion had been used. We can scarcely credit the statements of certain ancient writers that vinegar was used for dissolving rocks, but there is no doubt that over a thousand years ago highly combustible mixtures of natural products of the asphalt and petroleum types were employed. A manuscript dating from about the seventh century but probably of much earlier origin, known in brief English translation as the "Book of Fires" by Marcus the Greek, in its original Latin title the "Book of Fires to Burn Enemies," gives a large number of formulas for combustible materials for projectiles.

The invention of gunpowder brought the chemist into direct contact with war and a still closer contact took place when the modern high explosives were introduced. The late war saw the introduction of an entirely different phase of chemical military engineering, the employment of the toxic gases. The arts of peace, however, have demanded the greatest attention of the chemical engineer and the literature of works-procedure is very extensive. The present work does not deal with any particular procedure but discusses the methods of wide application, that is to say, gives the principles of works-operation very fully and clearly. It is the product of considerable thought and labor. It contains a very considerable amount of matter both relating to the history of the science and modern specific developments. It is a somewhat new venture into the field of chemical engineering and seems to be quite comprehensive in the treatment of the subject. It is to be commended to the attention of teachers of this branch of chemistry who may use it very satisfactorily in connecting the general principles which are here laid down and applying them to specific procedures in manufacture. HENRY LEFFMANN.

COURS PRATIQUE D'ÉLECTRICITÉ INDUSTRIELLE A L'USAGE DES ÉCOLES PRATIQUES DE COMMERCE ET D'INDUSTRIE, DES ÉCOLES PROFESSIONNELLES, DES ÉCOLES PRIMAIRES SUPERIEURES. Par Léon Bouthillon, Ingénieur en chef des Télégraphes, Répétiteur à l'École Polytechnique, et M. Goudonnet, Directeur de l'École pratique de Radioélectricité. In three volumes. Vol. I, Les Lois Fondamentales de l'Électricité. xiv–271 pages, 19 × 12 cm., paper. Price, 14 francs. Vol. II, Machines et Appareils Électriques. vii–324 pages, paper. Price, 20 francs. Vol. III, Applications de l'Électricité, in preparation. Paris, Gauthier-Villars et Cie., 1926 and 1927.

Properly learning a trade entails something more than the mastery of the technique of craftsmanship. That the rationale of an art cannot be ignored in the training of craftsmen is duly recognized by manufacturers who maintain systematic courses of instruction for their apprentices, and the existence of many night schools and correspondence schools which are maintained for those to whom the advantages of a well-planned apprentice course are not available.

The present work is one of the many texts which have appeared from time to time for instruction of that sort. Volume I deals with fundamental principles. Beginning with a chapter on mechanics, in which stress is laid on energy relationships, the theorems of electricity and magnetism are presented in the same orderly and deductive fashion as employed in formal treatises. The authors indeed show much ingenuity in devising convincing demonstrations in which only algebraic and trigonometric methods are employed. There are many line diagrams but no illustrations of actual apparatus. The absence of such illustrations will be of consequence only to the few readers who have no school contact. The general divisions of the subject are: Preliminary mechanical concepts; Currents, Electromotive force, Difference of potential; Ohm's and Joule's laws; Magnetism; Currents and the magnetic field; Alternating currents; Alternating-current circuits; Polyphase currents.

In the second volume, generators and motors are discussed at length. Following the usual order, the principles of the continuous-current generator are first considered and formulated with the aid of numerous diagrams.

Alternating-current machines followed by a variety of types of transformers then receive attention. Finally outlines of the principle and operation of the thermionic tube and other devices of the same nature, the principles of primary and secondary batteries and measuring instruments are described. In this volume a number of illustrations of the more important pieces of apparatus are given.

The work has especial value in presenting an elementary treatment in the same deductive order that a reader who may wish to advance farther will find in more advanced treatises. However, American readers of a French technical work will be mostly found in the college-trained class who would more likely choose such a well-known work as that of Eric Gerard, of the first volume of which, it may be mentioned, M. Bouthillon is editor.

LUCIEN E. PICOLET.

HYDROCHLORIC ACID AND SODIUM SULPHATE. By N. A. Laury. 127 pages, 25 illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1927. Price, $4.

This is one of the series of monographs issued by the American Chemical Society, the total issue now amounting to a considerable library of applied chemistry. The two substances considered are closely related in origin since the greater part of the hydrochloric acid of commerce is made by the action of sulphuric acid on common salt. This reaction was observed by Glauber in the latter half of the seventeenth century. It has been studied in much detail in recent years.

The material in the book is primarily, of course, the chemical engineering of the large-scale production. Principles of physical chemistry have so intruded into both research and technology that much reference to them cannot be avoided. In some cases, unnecessary information seems to be given. The law of mass-action and the principle of volatility as determining chemical action have been for many years in elementary text-books and a knowledge of them on the part of the trained chemists, who alone will use this book, may be assumed. So also unnecessary is the statement that perfectly anhydrous hydrogen chloride is without action on litmus. In this condition it is not really an acid.

A very large amount of information on the manufacture of the two substances is given. Factory details are presented fully, and numerous tables and illustrations add to the usefulness of the book. Sodium sulphate has long been known as Glauber's salt. Its laxative quality gained for it the title *sal mirabile*, in the days when doctors and pharmacists were brought up on Latin, but this term has lost its vogue. Magnesium sulphate has replaced it in regular medical practice. A certain amount of sodium sulphate is taken into the human system in connection with the cheaper forms of baking powder, which contain sodium aluminum sulphate, commonly known in trade as SAS. The salt figured prominently in French chemistry in the latter half of the eighteenth century as an intermediate in the manufacture of sodium carbonate.

This book will find excellent application in the factory in which hydrochloric acid is manufactured or in which either of the ingredients included are used.

HENRY LEFFMANN.

SWOOPE'S LESSONS IN PRACTICAL ELECTRICITY, an elementary text-book. Seventeenth edition, revised and enlarged. By Erich Hausmann, E.E., Sc.D., Professor of Physics at the Polytechnic Institute of Brooklyn and Fellow of the American Institute of Electrical Engineers. xiii–694 pages, 20 × 14 cm., illustrations, cloth. New York, D. Van Nostrand Company, 1927. Price, $2.50.

More than any other class of readers, those whose time is occupied with business pursuits who desire a working knowledge of the principles and the arithmetic of applied electricity require a most carefully planned presentation of the subject in order to cover it satisfactorily in their limited off-duty time. Though the present work may appeal to diversified classes of readers, it is more particularly designed for the purpose above specified. The original edition appeared in 1900. The many editions which have since appeared, including the present revision, bring the total issue to the handsome figure of one hundred thousand copies, which is ample evidence that it is adequately fulfilling its mission.

In its nearly seven hundred pages it is doubtful that any commercial application of electricity, its relation to fundamental principles, and its explanation in numerical values have been omitted. There are over five hundred line-cuts and half-tones, all of them good and most of them excellent. At the end of each chapter a collection of "questions" and "problems" provides the reader with an effective means of self-examination as he proceeds. Many experiments with illustrations are described which are clarifying to the reader who may not have facilities for conducting them as well as a valuable guide to the experimenter. In the present revision particular attention has been given to improvements in presentation of alternating currents, primary cells, electric lighting, electromagnetic induction, vacuum tubes, telegraphy and telephony and to radio-signalling.

The book, already well proven by earlier issues, will surely make many new friends, particularly among the self-taught readers who will scarcely fail to find it "made to order." LUCIEN E. PICOLET.

LUBRICATING GREASES. By E. N. Klemgard, B.Sc. 198 pages, 8vo. New York, The Chemical Catalog Company, Inc., 1927. Price, $5.50.

The extensive employment of machinery, especially in the motor car, has developed a corresponding interest and importance in the manufacture of lubricants. The practice relating to the axles of horse-drawn vehicles consisted in the employment mostly of ordinary crude greases of the farm products or mixtures of lime soap with oils. The production of petroleum in quantity led to its use in various forms. The present work gives an account of some of these early procedures and states that the modern greases are made from refined petroleum, high-class fats and a high quality of slaked lime. The processes used by the various manufacturers are largely trade secrets and hence little of value can be found in the literature. The present volume is believed to be the only one now in print which deals solely with grease and its uses. Its text is the product of many years of research with large manufacturing establishments in this field and much of the material has never before appeared in print. It therefore constitutes a fairly comprehensive exposition

of the theory, manufacture and uses of greases. Very many formulas are given so that the user of the book can find methods of preparing greases for every variety of purpose for which they are employed. Very extensive reference to patent literature is included. A good index is provided.

HENRY LEFFMANN.

A SYSTEM OF QUALITATIVE ANALYSIS FOR THE RARE ELEMENTS. By Arthur A. Noyes, Professor of Chemistry, California Institute of Technology, and William C. Bray, Professor of Chemistry, University of California. xii–536 pages, illustrations, 8vo. New York, The Macmillan Company, 1927. Price, $5.

The expression "rare elements" has acquired a relative value in chemistry. A considerable number of elements that were very rare fifty years ago are now familiar in many departments of chemical industry. In some cases the element was very abundant in combination, but its extraction was difficult and expensive. Industrial progress has given us many methods for the decomposition of minerals, and the very great abundance of aluminum in the modern day is an instance of the advance in the extraction of metals from their ores. Perhaps the most remarkable instance of a rare element becoming quite familiar and abundant is helium. Detected originally in the sun's chromosphere and assumed to be quite extra-terrestrial, it is now obtained in large quantities from some parts of the United States and a not uncommon sight is one of the great dirigibles floating along charged with this gas. It is unfortunate that one of the most useful of the metals, practically irreplaceable in many operations, is still much too rare for its satisfactory service. This is platinum.

The book in hand does not include the gaseous element just mentioned but applies to a large group of metals, some of which are quite common and are taken up in connection with the group to which the rarer members belong. In fact, it is an extension of the ordinary course of qualitative analysis so as to include a large number of elements which are passed over without notice in the ordinary college course. Qualitative analysis including the more common elements is the usual method of introduction to practical chemistry, but as generally presented it is a somewhat superficial treatment, and it is a question whether a limited number of experiments in quantitative analysis carefully supervised would not be a better initial training for the student.

The present book presents the results of experimental investigation carried out for thirty years by the authors and with trial of the processes by large numbers of associates and post-graduate students at the institutions with which the authors have been connected. As a result of this investigation there has been worked out in detail a system which includes nearly all the elements that are of a metallic nature and makes possible their detection in the presence of other elements though in very small proportion. As noted above, the term "rare elements" is somewhat arbitrary. A system of analysis in which these elements are included in the routine processes will be a great advance over the superficial qualitative course commonly followed, and the authors are to be commended for presenting such a thorough study of the subject as is included in this book.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report 275, The Effect of the Walls in Closed Type Wind-tunnels, by George J. Higgins. 18 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, ten cents.

A series of tests has been conducted during the period 1925–1927 by the Committee in the variable-density wind-tunnel on several airfoil models of different sizes and sections to determine the effect of tunnel-wall interference and to determine a correction which can be applied to reduce the error caused thereby. The use of several empirical corrections was attempted with little success. The Prandtl theoretical corrections give the best results, and their use is recommended for correcting closed wind-tunnel results to the conditions of free air.

An appendix is attached wherein the experimentally determined effect of the walls on the tunnel velocity very close to their surface is given. This is of special interest because a "scale effect" was found in the boundary layer with a change in the density of the tunnel air.

Report 276, Combustion Time in the Engine Cylinder and Its Effect on Engine Performance, by Charles F. Marvin, Jr. 16 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, ten cents.

As a part of a general program to study combustion in the engine cylinder and to correlate the phenomena of combustion with the observed performance of actual engines, this paper, which was outlined by Mr. S. W. Sparrow, and the work undertaken at the request of the Committee, presents a sketchy outline of what may happen in the engine cylinder during the burning of a charge. It also suggests the type of information needed to supply the details of the picture and points out how combustion time and rate affect the performance of the engine.

A theoretical concept of a flame front which is assumed to advance radially from the point of ignition is presented, and calculations based on the area and velocity of this flame and the density of the unburned gases are made to determine the mass rate of combustion. From this rate the mass which has been burned and the pressure at any instant during combustion are computed.

This process is then reversed in an effort to determine actual rates of combustion and flame velocities from the pressures as recorded on indicator diagrams.

The effects of different rates of combustion on engine performance are then discussed and the importance of proper spark advance is emphasized.

PUBLICATIONS RECEIVED.

The Making of a Chemical. A guide to works practice by E. I. Lewis, M.A., B.Sc., and George King, M.Sc., F.I.C. 288 pages, illustrations, 8vo. New York, John Wiley and Sons, Inc., no date. Price, $4.

The Propagation of Electric Currents in Telephone and Telegraph Conductors, by J. A. Fleming, M.A., D.Sc. Fourth edition, revised and extended. 422 pages, illustrations, plates, 8vo. New York, D. Van Nostrand Company, Inc., no date. Price, $8.

Pyroxylin Enamels and Lacquers, their raw materials, manufacture and

applications, by Samuel P. Wilson, M.A., Ph.D. Second edition, enlarged. 253 pages, 8vo. New York, D. Van Nostrand Company, Inc., 1927. Price, $3.50.

Molecular Physics and the Electrical Theory of Matter, by James Arnold Crowther, M.A., Sc.D. Fourth edition. 202 pages, illustrations, 12mo. Philadelphia, P. Blakiston's Son and Company, 1927. Price, $2.50.

Machinisme et Automatisme, par P. Maurer, chef du Service des Compteurs. 79 pages, 8vo. Paris, Gauthier-Villars et Cie., 1927. Price, 12 francs.

Canada Department of Mines, Mines Branch: Investigations of Fuels and Fuel Testing (Testing and Research Laboratories), 1925. 184 pages, illustrations, plates, 8vo. Ottawa, King's Printer, 1927.

U. S. Bureau of Mines: Mineral Resources of the United States, 1926, Part I: Arsenic in 1926, by C. V. Heikes. 8 pages. Gold, Silver, Copper, Lead and Zinc in the Eastern United States in 1926, by J. P. Dunlop. 8 pages. Part II, Slate in 1926, by A. T. Coons. 12 pages. Potash in 1926, by A. T. Coons. 10 pages. Washington, Government Printing Office, 1927. Price, for each pamphlet, five cents.

International Exhibition of Heavy Industries Sciences and Appliances, Liege, 1930. Preliminary announcement, administrators, classification. 30 pages, 8vo. Liege.

National Advisory Committee for Aeronautics: Technical Notes, No. 269, The Distribution of Loads between the Wings of a Biplane Having Decalage, by Richard M. Mock. 33 pages, illustrations, diagrams, photographs, quarto. Washington, Committee, 1927.

CURRENT TOPICS.

The Physical and Biological Effects of High-frequency Sound-waves of Great Intensity. R. W. Wood and A. L. Loomis. (*Phil. Mag.*, Sept., 1927.)—At the fiftieth anniversary of the founding of Johns Hopkins University, October, 1926, Professor Wood spoke on this very interesting subject. This paper presents a preliminary survey of the effects of sound-waves produced in an oil-bath by exciting a piezo-electric oscillator made of quartz with an alternating voltage of 50,000. A frequency of 700,000 was thus attained. The quartz was used in the form of circular discs. Their thicknesses ranged from 7 to 14 mm. Thus frequencies of 100,000 to 700,000 were obtained. The quartz disc rested in a vessel containing transformer oil on a piece of sheet lead, while upon it was placed a disc of very thin brass sheet that formed the second electrode. Interference experiments indicated that the amplitude of the vibration communicated from the crystal to the oil was about equal to a wave-length of light. The authors quote with approval C. V. Boys' terse description, "All acceleration and no motion." The general method was developed in 1917 by the French physicist, Langevin, whose theoretical work on magnetism is so well known. His purpose was to locate submarines by their reflecting a narrow beam of high-frequency sound-waves. The Poulsen arc which he used to excite the oscillations proved unsatisfactory and was replaced by the vacuum tube. This was used in the present experiments.

On thermodynamic grounds it was proved that light exerts a pressure on a surface upon which it falls. This pressure was first detected experimentally by Lebedew and was subsequently measured by Hull and Nichols in this country. With the waves set up in the oil the pressure of the sound vibration was readily demonstrable. A glass disc 8 cm. in diameter was put in the oil with its surface horizontal and above the quartz disc. From the plate at its centre projected upward a rod of the same substance carrying at its upper end a pan for weights. The pressure of the waves acting upward on the lower surface of the glass disc supported 150 grams on the pan. "The pressure is a maximum when the distance between the under surface of the plate and the upper surface of the quartz oscillator is a whole number of half wave-lengths. Under this condition the reflected wave strikes the oscillator when its phase is such as to reflect the wave back to the plate. The energy is thus imprisoned by multiple reflections between the vibrator and the plate, and the amplitude rises to a very high value. If the rod which supports the glass plate is held in the fingers and the plate pushed down gradually into the oil, a strong resistance is encountered periodically, as if the plate were breaking its way through a series of resisting films." Akin

to this pressure effect is the heaping up of a mound of oil when the waves are reflected at the upper surface of the liquid. "When the frequency of the electrical oscillation is tuned exactly to the natural frequency of the crystal plate the oil mound rises to a height of 7 cm., its surface erupting oil drops like a miniature volcano." Some of these reached a height of 30 or 40 cm.

Notable heating effects were obtained. When the temperature of the mound of oil was being taken, "though the mercury registered only 25°, the thermometer tube became so hot at the point where it was held between the thumb and finger that it had to be released. The heat, of course, is developed by friction between the vibrating glass stem and the skin of the fingers, or rather by the rapid pounding of the transverse vibrations." Again, "If a glass rod is drawn out into a long thread of the diameter of a horsehair, terminating in a pear-shaped bead, the heat developed, when the end of the thread is squeezed between the fingers and the bead dipped into the oil fountain, is so great that a groove with seared edges is left in the skin." An Erlenmeyer flask had its neck fused and a rod of the glass was drawn upward, its diameter at the end being ½ mm. The bottom of the flask was pushed into the vibrating oil and adjusted for maximum effect. Then a chip of wood pressed against the end of the rod smoked. The rod drilled its way into a glass plate held against it. With considerable pressure applied droplets of molten glass formed.

A test-tube filled with water was placed in a beaker containing water and ice to prevent any sudden rise of temperature. When the beaker was brought over the quartz disc and the waves passed through the beaker into the water in the test-tube, the energy thus transmitted was absorbed and the water rose in temperature at the rate of 3° a sec.

Emulsions and fogs resulted from the action of these high-frequency vibrations. "Stable emulsions resembling milk can be made of stearic acid or paraffin and water. A beaker of water with a layer of mercury at the bottom, under the influence of the vibrations, becomes first milky, then brown and finally black. At the end of twenty-four hours most of the mercury has settled, but a sufficient amount remains in suspension to make the water slightly turbid." The most spectacular experiment was the following: A glass tube, closed at one end and having a diameter of 25 mm., was drawn down to a diameter of 7 mm. The round bottom of the tube was lowered into the vibrating oil and adjustment of distance was made to secure the maximum effect. Oil is applied to the outside of the tube with a medicine dropper. "A very surprising thing happens. The oil spreads over the surface and is thrown out in jets of spray resembling smoke and a dense cloud gathers about the tube." The application of a flame causes a fine pyrotechnic display. The waves further produce flocculation of solids suspended in liquids, influence crystallization and accelerate certain chemical reactions.

Lower forms of life are destroyed by the disruptive action of the waves. Bacteria survive because they are so small that the whole of the organism is subjected to the same treatment. "Red blood corpuscles in a physiological salt solution are rapidly destroyed, the turbid liquid becoming as clear as a solution of a red aniline dye." Small fish and frogs are killed in one or two minutes, but mice recover from an exposure of twenty minutes.

It would seem that interesting and important avenues of approach have been opened by this, the first communication from the Alfred Lee Loomis Laboratory, Tuxedo, N. Y. G. F. S.

American Foundrymen's Association Honors Professor Outerbridge.—The Board of Directors of the American Foundrymen's Association acting on the recommendation of the Board of Awards has voted to award to Alexander Ewing Outerbridge, Jr., the Wm. H. McFadden Gold Medal of the American Foundrymen's Association. This award is being granted to Professor Outerbridge because of his contributions to the advancement of knowledge of cast-iron metallurgy. He was one of the pioneers in this country in application of science to the foundry industry and his researches paved the way for many developments of great value.

Professor Outerbridge was born in Philadelphia on July 31, 1850, and was educated at the Episcopal Academy of this city. In 1867 he was made assistant to Prof. John F. Frazer, who occupied the chair of physics and chemistry at the University of Pennsylvania. While acting in this capacity he attended lectures on physics and chemistry at the university. During 1868 he received an appointment as assistant in the Assay Laboratory of the U. S. Mint at Philadelphia where he worked for eight years. During this period he spent considerable time at the University of Pennsylvania in research work on the spectroscopic analysis of gold, silver, and other metals.

In 1879 Professor Outerbridge was sent to the New Orleans Mint to establish an assay department. Returning to Philadelphia, he was appointed metallurgist for A. Whitney and Sons Car Wheel Works, which position he held until 1888, when he became connected with William Sellers and Company, Inc., of the same city, as metallurgist, which position he still retains, although he retired from active work at the age of seventy-six.

In addition to his regular plant duties Professor Outerbridge has been identified with the work of The Franklin Institute of Philadelphia as professor of metallurgy and as a lecturer on industrial economics at the Wharton School of Finance of the University of Pennsylvania. In the cast-iron field Professor Outerbridge's research work on chilled cast iron, ferro-alloys, mobility of molecules in cast iron, strengths of cast-iron test bars as affected by tumbling and the growth of cast iron have been especially notable; and his findings in these researches have been used as the basis for further researches

of other workers. He was perhaps the first to see the value of X-rays in examination of castings, for in 1904 he showed examples of X-ray photographs of iron and steel and advocated their use in the examination of castings for defects.

For his original work in the molecular physics of iron he was awarded the John Scott Legacy Medal and Premium in 1897 by the City of Philadelphia on the recommendation of The Franklin Institute, and in 1904 the Elliott Cresson Gold Medal by The Franklin Institute.

Professor Outerbridge has been an extensive contributor to technical magazines and technical associations, some of his first papers were presented to the International Association of Testing Materials, The American Society for Testing Materials and the American Foundrymen's Association. His contributions to the JOURNAL OF THE FRANKLIN INSTITUTE number twenty-eight and deal chiefly with subjects relating to metallurgy and the foundry.

THE FRANKLIN INSTITUTE

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